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Underplanting cherrybark oak (*Quercus pagoda* Raf.) seedlings on a bottomland site in the southern United States

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Abstract. We initiated a study on a bottomland site in the southern United States to examine the effects of Japanese honeysuckle (*Lonicera japonica* Thunberg) control and seedlings of two root classes on survival and growth of underplanted cherrybark oak (*Quercus pagoda* Raf.) seedlings. Three honeysuckle control treatments were assigned to nine 0.5-ha plots in a stand harvested to 30% residual stocking. Treatments included a spring 1997 herbicide application (Escort®, metsulfuron-methyl), a similar application in the late summer of 1997, and a control (no herbicide application). In 1998, half of each treatment plot was planted with seedlings having four or more first-order lateral roots >1 mm in diameter, while the other half of each plot received seedlings with fewer than four lateral roots. Four years after treatment, the early season application reduced honeysuckle biomass 60% relative to the other treatments, but we did not observe a survival or growth response by underplanted seedlings. Three years after establishment, seedlings that initially had four or more lateral roots were 16% taller and 18% larger in root-collar diameter than seedlings in the other class, but these differences were primarily due to initial size differences maintained through the study period. Over all treatments, oak seedlings averaged 87% survival while showing a 300% increase in height and a 170% increase in root-collar diameter 3 years after planting. Our results suggest that partial stand harvesting followed by underplanting may be a viable approach for establishing cherrybark oak reproduction on bottomland sites of the southern United States.

Introduction

Numerous forest types throughout temperate regions of the globe are distinguished with a high component of oak (*Quercus* spp.) (Johnson et al. 2002). In spite of the prevalence of the genus on a wide range of ecological sites, problems and failures regenerating oak stands appear nearly universal (Lorimer 1993; Johnson et al. 2002). Regeneration difficulties have been noted persistently and extensively with recent examples such as northern red oak

(*Q. rubra* L.) in the northeastern United States (Zaczek 2002), pedunculate oak (*Q. robur* L.) in southern Sweden (Löf et al. 1998), Garry oak (*Q. garryana* Dougl. Ex Hook.) in western Canada (Fuchs et al. 2000) and Liaotung oak (*Q. liaotungensis* Koidz.) in China (Li and Ma 2003). In the southern United States, several oak species are endemic to the alluvial sites of river floodplains. These bottomland oaks can be particularly difficult to regenerate, and current management practices have not proven reliable for maintaining a significant oak component in future stands (Meadows and Stanturf 1997; Lockhart et al. 2000). Alternative silvicultural practices that reliably produce well-stocked pools of competitive oak reproduction are desperately needed for management of bottomland hardwood forests.

Underplanting has been a relatively successful approach for establishing artificial reproduction in upland oak stands of the north-central and eastern United States (Johnson et al. 1986; Tworkoski et al. 1986; Teclaw and Isebrands 1993). Prescriptions for underplanting upland stands usually involve removal of the midstory and partial removal of the overstory to increase understory resource availability (light, soil moisture, nutrients), followed by planting of relatively large, vigorous seedlings (Dey and Parker 1997; Spetich et al. 2002). However, understory competition control is usually required on high quality upland sites to ensure adequate survival and growth of the outplanted seedlings (Johnson et al. 1986; Schlesinger et al. 1993; Spetich et al. 2002). After the underplanted seedlings are well established and attain a competitive size, they are released by harvesting the overstory (Johnson 1984; Johnson et al. 1986).

Though the efficacy of underplanting has been demonstrated for regenerating upland oak forests, application of similar techniques have not been widely examined for bottomland oaks (Nix and Cox 1987; Chambers and Henkel 1988). Because soil on bottomland sites can be highly productive, foresters attempting to regenerate oak often encounter many of the same obstacles described for mesic upland sites. A midstory layer of shade-tolerant species often develops on these sites reducing understory light availability to levels below what is necessary to sustain vigorous growth by oak seedlings (Lockhart et al. 2000). If understory resources are increased by removing the midstory canopy, fast-growing intolerant species quickly establish and provide competition for oak seedlings (Nix and Cox 1987; Hodges and Gardiner 1993). Furthermore, bottomland hardwood stands are characteristically rich in aggressive woody vines which can quickly overtop reproduction and delay seedling development. In addition to numerous native vines, the invasive, exotic vine Japanese honeysuckle (*Lonicera japonica* Thunberg) is naturalized throughout the southern United States where it is thought to restrict development of oak reproduction on some bottomland sites. This particular vine readily establishes after disturbance, grows aggressively when released, and can quickly overtop slow growing hardwood regeneration (Bruner 1967; Schmeckpeper et al. 1987).

In spite of continual problems with regenerating bottomland oaks through conventional practices, few attempts have been made to investigate the use of underplanting for establishing vigorous reproduction. We installed a field study to examine the feasibility of underplanting in bottomland hardwood stands to increase the establishment and vigor of oak reproduction. The primary objectives of this research were to test the effects of Japanese honeysuckle control treatments and two seedling classes, grouped by number of lateral roots, on establishment and growth of cherrybark oak (*Quercus pagoda* Raf.) seedlings underplanted in a partially harvested stand. This manuscript reports on the early establishment and growth of underplanted cherrybark oak seedlings in relation to pre-plant honeysuckle control treatments and seedling classes.

Materials and methods

Study site

The study was established in the Little Missouri River floodplain of Clark County, Arkansas, USA (latitude = 33°87′ N, longitude = 93°28′ W). Soils on this alluvial site were mapped as Sardis and Guyton series (Hoelscher 1987). The Sardis series is classified as a fine-silty, siliceous, active, thermic Fluvaquentic Dystrudepts, while the Guyton series is classified as a fine-silty, siliceous, active, thermic Typic Glossaqualfs. Mean annual rainfall on the site is 1315 mm, and this precipitation is distributed across most months of the year. Maximum monthly air temperatures occur in July averaging 27.5 °C, minimum temperatures occur in January averaging 5.5 °C (Hoelscher 1987).

A mature, mixed, bottomland hardwood stand composed primarily of sweetgum (*Liquidambar styraciflua* L.) and several oak (*Quercus* spp.) species occupied the study site (Table 1). Basal area averaged 26 m^2 ha^{-1}, with oaks comprising 26% of the basal area and sweetgum comprising 19%. Tree species common in the midstory included American holly (*Ilex opaca* Ait.), American hornbeam (*Carpinus carolinina* Walt.), eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), winged elm (*Ulmus alata* Michx.) and American elm (*Ulmus americana* L.). This well-developed midstory layer of shade tolerant

Table 1. Pre-harvest (1996) and post-harvest (1997) conditions (mean ± standard error) in a mixed, bottomland hardwood stand of the Little Missouri River floodplain, Clark County, AR, USA.

	Pre-harvest	Post-harvest
Stand density (stems ha^{-1})	103 ± 27	11 ± 1
Mean stem diameter (cm)	39.7 ± 0.7	54.2 ± 1.2
Basal area (m^2 ha^{-1})	26.3 ± 0.8	7.8 ± 0.4
Light availability (%)	4 ± 1	49 ± 5

Table 2. Biomass of all understory plants and Japanese honeysuckle relative to partial cutting and vegetation control treatments in a mixed bottomland hardwood stand.

Treatment	Pre-harvest	Post-harvest
Understory biomass (kg ha^{-1})z		
Early season application	163 ± 26 a*	3239 ± 393 a
Late season application	201 ± 38 a	4648 ± 399 a
Control	239 ± 48 a	4128 ± 409 a
Japanese honeysuckle (kg ha^{-1})		
Early season application	58 ± 15 a	191 ± 61 b
Late season application	65 ± 12 a	612 ± 104 a
Control	68 ± 16 a	427 ± 81 a

*Means in a column followed by the same letter are not different ($p < 0.05$).

trees contributed to limiting light availability in the understory to about 4% of that available in the open (Table 1). Japanese honeysuckle was a primary component of the understory flora where it comprised over 30% of all biomass (Table 2).

Study design

A series of nine, 0.5-ha plots (60.4 m × 80.5 m) were delineated on the site in June 1996 (Table 3). The nine plots were arranged in three blocks based on micro-topographical relief on this bottomland. Plots were randomly assigned one of three honeysuckle control treatments: (i) an early season herbicide application (May 1997), (ii) a late season herbicide application (August 1997), and (iii) a control – no herbicide applied. The herbicide solution, which was broadcast with backpack sprayers, was 70 g (product) per ha Escort®[1] (metsulfuron-methyl) (DuPont, Wilmington, DE), 1.5% Red River 90 non-ionic surfactant (Brewer International, Vero Beach, FL), and 280.5 l of water. Prior to herbicide application (October 1996), two-thirds of the treatment plots (those scheduled to receive a herbicide application) were harvested to 30% residual overstory stocking (Goelz 1995). Residual trees were selected based on species and distribution, favoring trees with high crown vigor and good bole quality for retention (Table 1). Additionally, midstory stems > 2.5 cm dbh were cut during the harvesting operation. Partial cutting of these plots was done to promote foliage growth by Japanese honeysuckle for the herbicide application. To maintain consistent light regimes across the study, a 40-m buffer around all plots was harvested as described above. Because competition from honeysuckle and other vegetation would readily establish, it would have been operationally unwise to harvest and wait a year before underplanting oak

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Table 3. Timeline of study establishment, partial harvesting, herbicide treatment, underplanting and sampling activities.

Activity	Time
Plot, split-plot and reference point establishment	June 1996
Pre-treatment stand and understory biomass sampling	July 1996
Partial overstory harvest	October 1996
Early season broadcast application of herbicide	May 1997
Late season broadcast application of herbicide	August 1997
Partial overstory harvest of control plots	October 1997
Cherrybark oak seedling underplanting	February 1998
Post-treatment biomass sampling	August 2000

seedlings in control plots. So, to avoid an early release of competition in control plots, these plots were harvested in October 1997. Delaying the partial harvest of control plots ensured the underplanted seedlings were not established in competition released a year earlier.

In February 1998, 1–0 bareroot, cherrybark oak seedlings were underplanted in all 9 plots. Prior to planting, seedlings were separated into two classes based on number of first-order lateral roots >1 mm in diameter. The first group included seedlings with four or more first-order lateral roots, and the second group included seedlings with fewer than four first-order lateral roots. Plots were split so that half of each treatment was planted with seedlings having four or more first-order lateral roots, while the other half of each plot received seedlings with fewer than four lateral roots. All seedlings were hand planted with hardwood planting shovels on a 3.7×3.7 m spacing, and 100 seedlings of both root classes were flagged in each plot to serve as measurement seedlings.

Sampling and measurements

Height (cm) and root-collar diameter (mm) of each flagged seedling were measured after planting and annually after the first 3 post-planting growing seasons. Seedling survival was assessed at the end of each growing season, while "free-to-grow" status, and honeysuckle contact were recorded after the third growing season. We designated seedlings "free-to-grow" if they were not overtopped by other understory vegetation. As an index of the amount of Japanese honeysuckle competing directly with planted cherrybark oak seedlings, we noted when honeysuckle vines twined around or were in above-ground contact with planted seedlings.

A systematic grid of six reference points was established in each 0.5-ha treatment plot to serve as locations for biomass and light availability sampling. For understory aboveground biomass, a random azimuth and distance from the reference point was selected for placement of a 1-m^2 sample frame, while a second 1-m^2 sample frame was positioned the same distance but on an azimuth

180° from the first sample. Thus, two biomass samples were collected near each reference point during each sample period. Understory aboveground biomass was quantified in July 1996 (pre-treatment) and August 2000 (post-treatment) by clipping all vegetation in 12, 1-m^2 sample frames positioned in each treatment plot. To avoid re-sampling an area, sample frames in August 2000 were positioned at a randomly selected azimuth that differed from the earlier sample period. Clipped vegetation was bagged, transported to the laboratory, and dried at 50 °C until desiccated to constant dry mass. Understory light availability was recorded at each sample point prior to treatment, and during the second growing season. Photosynthetically active radiation (PAR) was measured with a Li-Cor® LI-191SA line quantum sensor (Li-Cor, Inc., Lincoln, NE) 1.1 m above groundline at each of the 54 reference points. This sampling was conducted at solar noon ±1 h on cloud-free days in July 1996 and August 1999. PAR measurements collected in treatment plots were expressed as a percentage of similar measurements recorded in a nearby opening.

Statistical analyses

Treatment effects of honeysuckle control and seedling class on survival, height and root-collar diameter of cherrybark oak seedlings were partitioned with analysis of variance according to a randomized complete block design with split-plots. For these analyses, honeysuckle control treatment served as the whole-plot effect and seedling type was the split-plot effect. We also analyzed treatment effects on relative height and diameter growth of seedlings. Relative height growth for a year was calculated as: $(\text{height}_{t_{i+1}} - \text{height}_{t_i})/\text{height}_{t_i} \times 100$. A similar equation was used to calculate relative root-collar diameter growth. Analyses were conducted for each year on plot means at an alpha level of 0.05. Plot means used for analyses on height, root-collar diameter and relative growth were computed from observations on seedlings surviving the three growing seasons.

Results

Understory response to competition control

Prior to treatment, understory vegetation had an average biomass of 201 kg ha^{-1}, of which Japanese honeysuckle comprised 31% (Table 2). Partial harvesting reduced canopy cover and increased light availability in the understory from 4% to nearly half of full sunlight (Table 1). Understory vegetation, comprised of herbaceous species, grasses, sedges, vines and sprouts from woody vegetation, responded vigorously to partial cutting in the stand with biomass increasing nearly 20-fold during the four-year period following harvest (Table 2). Broadcast herbicide treatments did not differ in their effect on total understory biomass, but the early season application did appear more effective against Japanese honeysuckle. Four years after application, Japanese honeysuckle biomass in plots receiving the early season application was reduced more than 60% relative to the control and late season application treatments (Table 2). By the end of the third growing season, honeysuckle had grown in contact with 38% of the seedlings established in plots receiving the early season application. This is in contrast to 70% contact in control and late season application treatments ($p = 0.015$).

Seedling survival

Underplanted cherrybark oak seedlings showed uniform survival through the first three growing seasons as mortality averaged 13% across the site (Table 4). Seedling survival was not impacted by honeysuckle control or seedling lateral root class (Table 4).

Seedling height and diameter

Initial height and diameter of planting stock differed with seedling root class (Figure 1). Seedlings with four or more lateral roots were 9% taller and had 32% larger root-collar diameters than seedlings with fewer than four lateral roots. These initial differences in height and diameter were maintained through three growing seasons. By the end of the third growing season, seedlings with four or more lateral roots were 16% taller and had an 18% larger root-collar diameter than the stock with fewer lateral roots (Figure 1).

For all treatments, mean height of underplanted seedlings increased nearly 300% during the 3 year study period, and root-collar diameter showed an increase of over 170% (Figure 1). Application of honeysuckle control

Table 4. Results of analysis of variance for herbicide treatment and seedling class effects on survival (%) (mean ± standard error) of cherrybark oak seedlings during the first 3 years of establishment in a partially harvested bottomland hardwood stand.

Treatment effect	Year 1	Year 2	Year 3
Honeysuckle control			
Early season application	97.8 ± 0.59 a*	93.5 ± 1.16 a	88.7 ± 1.53 a
Late season application	96.4 ± 0.65 a	91.0 ± 1.08 a	85.8 ± 1.48 a
Control	97.7 ± 0.62 a	92.8 ± 1.30 a	88.3 ± 2.85 a
p-value	0.0620	0.1601	0.2537
Seedling class			
≥4 lateral roots	97.7 ± 0.48 a	93.4 ± 1.13 a	89.7 ± 1.64 a
<4 lateral roots	96.9 ± 0.55 a	91.4 ± 0.71 a	85.5 ± 1.37 a
p-value	0.3794	0.3330	0.2024

*Means in a column followed by the same letter are not different ($p < 0.05$).

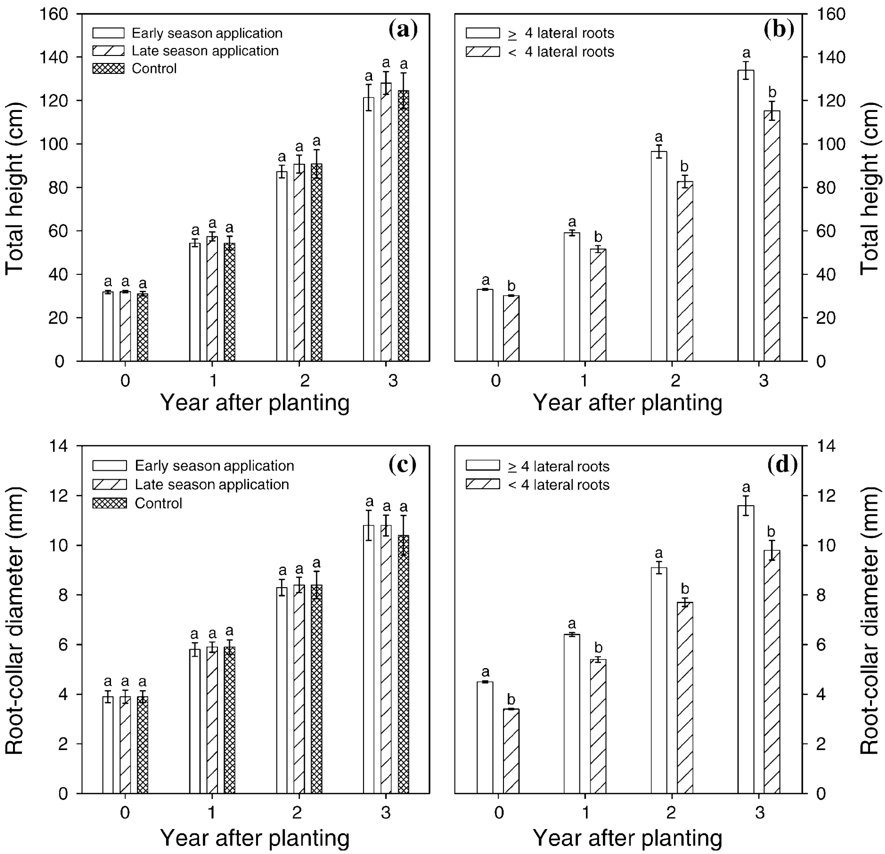

Figure 1. Variation in mean total height (a, b) and root-collar diameter (c, d) with time after planting as affected by competition control treatment (a, c) and number of lateral roots (b, d). Vertical bars sharing the same letter within a given time period are not different ($p < 0.05$).

treatments did not influence height or diameter of underplanted cherrybark oak seedlings (Figure 1). Seedlings established in plots receiving the early and late season herbicide application of honeysuckle control exhibited similar height and diameter to seedlings established in untreated plots.

Seedling relative growth

Japanese honeysuckle control and seedling class did not influence relative height growth of underplanted cherrybark oak seedlings. Across the study site, relative height growth of seedlings averaged 81% during the first growing season, 68% during the second growing season, and 41% during the third growing season (Figure 2). Though initial height of planted seedlings averaged

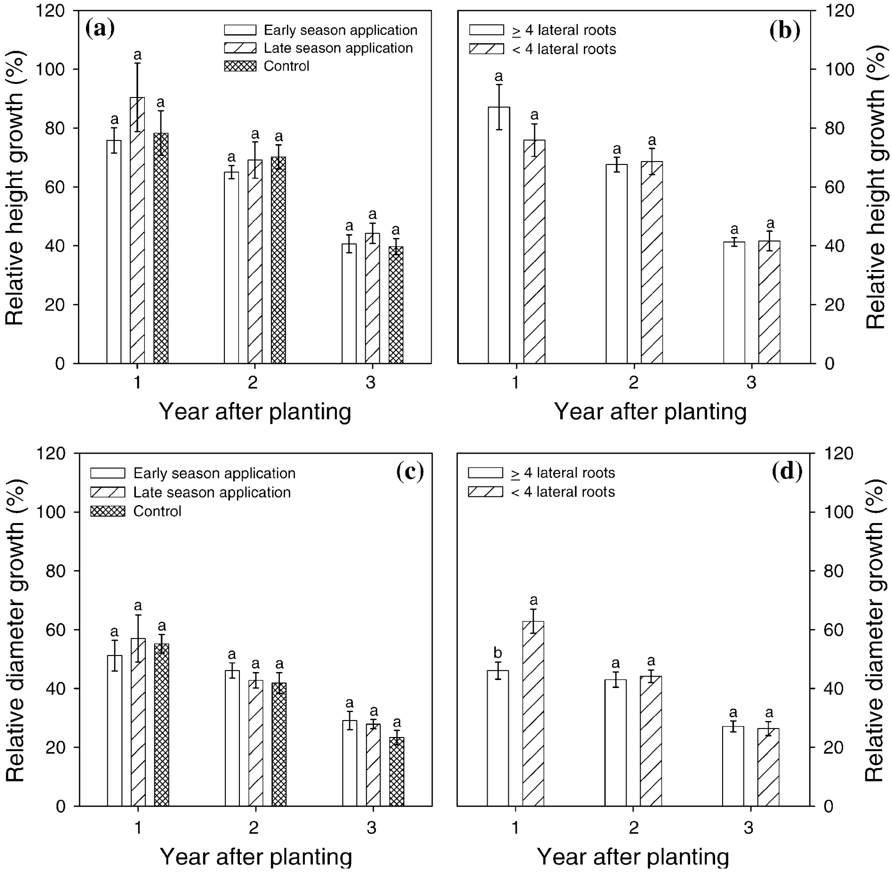

Figure 2. Variation in mean relative height (a, b) and root-collar diameter growth with time after planting as affected by competition control treatment (a, c) and number of lateral roots (b, d). Vertical bars sharing the same letter within a given time period are not different ($p < 0.05$).

less than 35 cm, height growth of cherrybark oak seedlings beneath the partial canopy proceeded vigorously such that 66% of the established stock had grown into a 1 m or taller height class by the end of the third growing season (Figure 3). Additionally, 78% of surviving seedlings were "free-to-grow" at the end of the third growing season. Underplanted seedlings with fewer than 4 lateral roots averaged 36% greater first-year root-collar diameter growth than seedlings with four or more lateral roots (Figure 2). This growth difference diminished after the first growing season, and seedlings exhibited similar root-collar growth regardless of seedling class or honeysuckle control treatment.

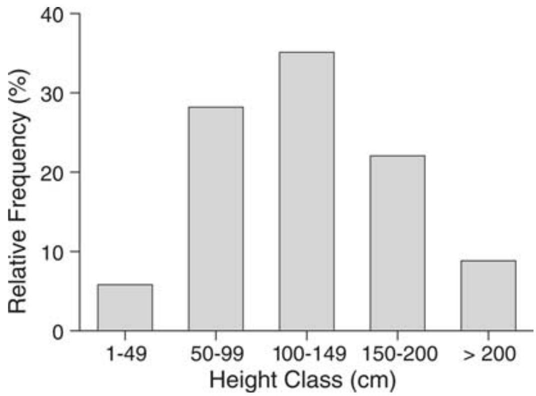

Figure 3. Height class distribution of underplanted cherrybark oak seedlings 3 years after establishment in a partially harvested bottomland hardwood stand. At time of planting, all seedlings were in the 1–49 cm height class.

Discussion

Seedling response to honeysuckle control

Oak seedling underplanting recommendations developed for upland sites typically involve some level of understory vegetation control (Johnson et al. 1986; Dey and Parker 1996; Weigel and Johnson 1998) to reduce competition that may respond faster to overstory release than the oak seedlings (Johnson 1984; Hodges and Gardiner 1993). Few workers have studied bottomland hardwood seedling response to vegetation control, particularly in underplanted stands. Nix (1989), who worked in a clearcut bottomland hardwood stand, documented a positive growth response by planted cherrybark oak seedlings following release with an application of a broad-spectrum herbicide. The vegetation control treatment applied in our study differed from other approaches in that it was not directed at woody seedlings, saplings or sprouts, rather it targeted the invasive vine Japanese honeysuckle. We found the early season herbicide application substantially reduced Japanese honeysuckle biomass through the third growing season after underplanting. Additionally, seedlings established in plots receiving this treatment were 45% less likely to be in contact with honeysuckle at the end of the third growing season. In contrast, late season herbicide application did not provide effective control of honeysuckle, presumably because of the high volume of herbaceous biomass that developed on the site between May and August. This herbaceous cover probably protected honeysuckle vines from receiving sufficient herbicide to achieve long-term control. Though the early season application effectively reduced honeysuckle biomass and reduced above-ground contact of seedlings by honeysuckle, we did not observe a concomitant increase in survival or growth by underplanted oak seedlings. Additionally, we observed a similar percentage of "free-to-grow" seedlings in control plots as we did in plots receiving honeysuckle control. Our observations on above-ground understory biomass verified that the Escort herbicide treatment provided narrow spectrum weed control and was ineffective against other understory vegetation.

Previous research by Dillenburg et al. (1993) confirmed that Japanese honeysuckle can interfere with seedling growth of sweetgum, a common bottomland hardwood species that grows in association with cherrybark oak. To examine more directly the effect of honeysuckle on underplanted cherrybark oak seedlings, we conducted a *t*-test to compare third-year heights and diameters of seedlings in contact with honeysuckle to those of seedlings that were not in contact with honeysuckle. Contrary to our expectations, seedlings growing in contact with Japanese honeysuckle were on average 29 cm or 27% taller ($p < 0.0001$) and 1.8 mm or 19% larger ($p < 0.0001$) in root-collar diameter than seedlings that were not in contact with the vine. This finding conflicts with those of Dillenberg et al. (1993), but they noted that Japanese honeysuckle impaired above-ground growth of sweetgum primarily through root competition. In fact, they demonstrated that sweetgum seedlings exposed to only above-ground interaction with the vine did not show reduced height growth (Dillenburg et al. 1993), and may have actually increased carbon allocation to above-ground biomass components, particularly to leaves and branches (Dillenburg et al. 1995). A similar allocation response may have increased stem length in our underplanted cherrybark oak seedlings, but such an allocation response would not explain the positive diameter growth we observed. Though we did not examine seedling biomass accumulation or below-ground competition to confirm the mechanism for this response, a more plausible explanation for the enhanced growth we observed could involve micro-environmental gradients on our study site. Growth of bottomland tree species varies considerably in response to edaphic factors in floodplains (Hodges 1997). Cherrybark oak, in particular, thrives best on well-drained, loamy ridges in floodplains. On our study site, the densest growth of Japanese honeysuckle also appeared to occur on these same microsites. Thus, microsites supporting the best growth of cherrybark oak seedlings may also be microsites where seedlings are most likely to encounter Japanese honeysuckle.

Seedling response by type

Workers studying use of underplanting to establish oak reproduction in other regions have often investigated effects of seedling morphology on field performance of underplanted stock (Johnson 1992; Teclaw and Isebrands 1993; Gordon et al. 1995; Dey and Parker 1997). Through their research, several of these workers have emphasized the importance of a well-developed root system to outplanting success of underplanted seedlings (Johnson 1984, 1992; Johnson et al. 1986; Teclaw and Isebrands 1993; Weigel and Johnson 1998). Though a well-developed root system is considered critical to outplanting success, attempts to use number of first-order lateral roots as an index to field performance of underplanted oak seedlings have not yielded results as definitive as those reported for northern red oak seedlings established on open sites (Thompson and Schultz 1995; Dey and Parker 1997). Teclaw and Isebrands (1993), working in an underplanted stand in Wisconsin, USA, found that third-year heights of northern red oak seedlings with five or fewer first-order lateral roots were smaller than that of seedlings that had larger root systems. However, the height difference they reported appeared to be attributable primarily to initial seedling heights and seedling height growth during the first two growing seasons. By the third growing season, height growth did not differ among seedling classes based on first-order lateral roots (Teclaw and Isebrands 1993). In our study, separating cherrybark oak seedlings into two arbitrary classes based on number of first-order lateral roots did not account for variation associated with third-year survival or relative growth rates, but we recognize that seedling classes based on a different threshold number of roots may provide different results. We did observe differences in third-year heights and root-collar diameters of underplanted seedlings between the two seedling classes, but differences were largely due to initial differences in seedling height and diameter. Additionally, Dey and Parker (1997), who studied northern red oak seedlings underplanted in Ontario, reported a weak positive correlation between second-year height of seedlings and number of first-order lateral roots, and their research revealed that root-collar diameter was a stronger predictor of second-year height than was number of first-order lateral roots. Likewise, Spetich et al. (2002) observed that initial seedling diameter was strongly correlated with survival and ultimately competitive capacity of underplanted northern red oak. We did not examine the effect of initial root-collar diameter on seedling growth in this study. Nevertheless, it appears that seedling characteristics essential to superior field performance in understory environments differ from those that drive field performance in open environments.

Underplanting cherrybark oak

Findings from research conducted in upland hardwood stands indicate that partial harvesting can provide a favorable understory environment for development of oak seedlings if stand stocking is reduced to a level between 40 and 60% (Dey and Parker 1996; Weigel and Johnson 1998; Spetich 2002). Cherrybark oak seedlings examined in this study were established beneath the canopy of a stand that was harvested to 30% stocking increasing light availability to near 50% of that available in the open. This level of light availability is near optimal for cherrybark oak seedlings raised beneath artificial shade (Gardiner and Hodges 1998), and appeared sufficient to achieve high levels of survival and stem growth of underplanted seedlings in the current study. We cannot explain why relative height growth appeared to decrease over time, but the growth rate we observed matched or exceeded reported height growth rates for other oak species (Johnson 1984). For example, relative height growth of northern red oak underplanted in Ontario averaged about 46% during the establishment year (Dey and Parker 1997), while Tworkoski et al. (1986) noted less than 50% height growth on northern red oak and white oak (*Quercus alba* L.) during 3 years of growth beneath a Virginia, USA shelterwood. In contrast to those reports, cherrybark oak seedlings in this study developed rapidly beneath the partial canopy as two-thirds of the planted stock attained a size class greater than 100 cm during the first three growing seasons. Additionally, 78% of the surviving cherrybark oak seedlings were "free-to-grow" after three growing seasons. At the 3.7 m $\times$ 3.7 m spacing used in our study, over 550 cherrybark oak seedlings per ha would be strong competitors for successful canopy recruitment if released from overstory shade.

Summary

The partial harvesting and underplanting approach we investigated appears promising as a practice to establish cherrybark oak reproduction on bottomland sites in the southern US. We demonstrated that the invasive vine Japanese honeysuckle, if present in the understory of mature stands, will respond vigorously to canopy disturbance, but an early application of a suitable herbicide solution will effectively reduce biomass of the species. However, the presence of honeysuckle on bottomland sites at levels recorded in this study may not be detrimental to seedling establishment when using vigorous planting stock. Additionally, the number of first-order lateral roots does not appear to be a robust indicator of potential field performance of underplanted cherrybark oak seedlings. Future research will be needed to identify morphological or physiological characteristics that are predictive of field performance of underplanted cherrybark oak seedlings to realize further gains in survival or growth.

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