EFFECTS OF PLANTING STOCK ON GROWTH AND SURVIVAL IN AN ARTIFICIALLY REGENERATED SHORTLEAF PINE FOREST IN THE SOUTHERN APPALACHIAN MOUNTAINS

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ABSTRACT

Shortleaf pine (*Pinus echinata* Mill.) is a widely distributed species and was historically a prominent component of southern Appalachian forests but has continued to decline throughout the region. The objectives of this case study were to examine how survival and growth of artificially regenerated shortleaf pine seedlings varied between planting stocks (containerized verses bareroot) and quantify and characterize competition from hardwood species following two-aged regeneration harvests that included site preparation activities and release treatments. Three-year survival was high for both containerized (100 percent) and bareroot stock (96 percent), while 3-year height and ground line diameter were greater for bareroot stock. The regeneration harvest stimulated the growth and recruitment of mesophytic hardwood species that will compete with shortleaf pine and likely influence future growth and survival. Efforts to successfully regenerate and restore mixed shortleaf pine/oak stands necessitate the reintroduction of disturbance via silvicultural treatments that include harvesting, site-preparation, chemical or mechanical release treatments, and/or prescribed fire over a long period of time.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.) is the most widely distributed southern yellow pine species. Found in 22 states in a variety of forest types and geographic conditions, shortleaf pine was historically a prominent component of southern Appalachian forests (Anderson and others 2016, Oswalt 2012). It is estimated that prior to the European colonization of North America, shortleaf pine and shortleaf pine/oak forest types covered roughly 24 to 28 million hectares (Anderson and others 2016). However, shortleaf pine has declined dramatically throughout the region (Guldin and Black 2018). Today, these forest types only cover 2.5 million hectares, with shortleaf pine forest types covering an estimated 1.3 million hectares and shortleaf pine/oak forest types covering 1.2 million hectares (Guldin and Black 2018, Oswalt 2012). Factors such as land use change, conversion to high-yield plantations, southern pine beetle (*Dendroctonus frontalis*) outbreaks, and changes in the historic disturbance regime, including fire suppression, are the leading causes associated with the decline throughout the range (Guldin 2007).

The abundance, dominance, and relative importance of shortleaf pine varies widely across its natural range. In the western portion of the range (e.g., Arkansas), pure shortleaf pine stands are common, while in the Southern Appalachian Mountains, shortleaf pine exists primarily as a component of mixed pine/oak (*Quercus* L.) forest types, with common associates including pitch pine (*P. rigida* Mill.) and dry oak species, including scarlet (*Q. coccine*a Menchh.), chestnut (*Q. montana* L.), white (*Q. alba* L.), and black (*Q. velutina* Lam.) oak. In the Southern Appalachian Mountains, shortleaf pine and shortleaf pine/oak forests are primarily found on exposed, convex landforms at low elevations as well as upper slopes that are low in fertility and experience a deficit in soil moisture during the growing season (Simon and others 2005). Similar to upland oak forests prevalent across much of the Eastern United States, shortleaf pine/oak forests are successional, with persistence at the stand- and landscape-level dependent on frequent low- to moderate-severity disturbance (Brose and others 2001). Without disturbance to the upper and lower canopy layers, these xeric pine/oak forests transition to forests dominated by oaks and eventually shade-tolerant, mesophytic species (Harrod and others 1998, Nowacki and Abrams 2008).

The regeneration and restoration of shortleaf pine/oak forests in the Southern Appalachians is complicated by competition from fast-growing hardwood species, such as sweetgum (*Liquidambar styracifula* L.), red maple (*Acer rubrum* L.), and yellow-poplar (*Liriodendron tulipifera* L.) (Clabo and Clatterbuck 2020a, Jensen and others 2007, Schnake

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and others 2021). As such, site preparation and release treatments are likely needed to ensure shortleaf pine remains competitive and to facilitate recruitment into the canopy over time (Clabo and Clatterbuck 2020b). Further complicating restoration efforts is that existing pine/oak stands in the Appalachians contain few shortleaf pine seed trees. This sparse shortleaf pine overstory is unlikely to provide for the timely and sufficient seed source necessary to secure natural regeneration, making artificial regeneration a necessary component of shortleaf pine/oak restoration treatments.

Artificial regeneration of shortleaf pine is usually conducted after manipulating the density and stocking of the overstory (Clabo and Clatterbuck 2020a, Kabrick and others 2015, Waldrop and others 1989). Combined across species, southern pines regenerated from containerized stock have better performance on poor sites, but differences in performance between planting stocks are ameliorated on sites of higher productivity (Barnett and Brissett 2004, Barnett and McGilvray 1993, Boyer 1988, Ruehle and others 1981, South and others 2012). Root systems of containerized seedlings are often less damaged than bareroot seedlings during lifting operations at the nursery, which should confer an advantage (both survival and growth) over bareroot stock during outplanting (Barnett and Brisette 1986). Although containerized seedlings are preferred to artificially regenerate longleaf pine (*P. palustris* Mill.) (Barnett and McGilvray 1997), information on the potential advantages and disadvantages of the different planting stocks specific to shortleaf pine is sparse, especially across a wide range of environmental conditions.

Restoration of shortleaf pine and shortleaf pine/oak forests in the mountainous regions east of the Mississippi River, will be challenged by myriad factors, including strong and complex topographic, edaphic, and climatic gradients, all of which influence species composition, competitive dynamics, and post-disturbance stand dynamics. Although literature that guides the ecology and management of shortleaf pine forests in the western portion of its range is abundant (Guldin 2019, Kabrick and others 2007), comparatively few studies have been conducted in the Appalachian Region (Clabo and Clatterbuck 2020a, 2020b; Waldrop 1997). As such, basic information that guides the restoration of shortleaf and shortleaf pine/oak forests, including efficacy of natural and artificial regeneration methods, across a wide range of environmental gradients and stand conditions in the eastern portion of shortleaf pine's range is lacking. The objectives of this observational study are to examine how the survival and growth of artificially regenerated shortleaf pine seedlings varied between planting stocks (containerized verses bareroot) and quantify and characterize competition from hardwood species following a two-aged regeneration harvested in a degraded shortleaf pine/oak stand in the Southern Appalachians.

MATERIALS AND METHODS

Study Area

This study was conducted on two sites on the Grandfather Ranger District on the Pisgah National Forest in western North Carolina. The Grandfather Ranger District lies within the Blue Ridge Escarpment, where the Blue Ridge Mountains meet the Piedmont. The landscape is characterized by the southwest to northeast aspects typical of the Blue Ridge Mountains. Elevations ranged from 400 to 550 m and slopes ranged from 11 to 47 percent. The climate is characterized as generally warm and humid, with annual precipitation averaging (1991-2020, Old Fort AG 3W climate station) 1421 mm and minimum and maximum temperatures averaging 6.1 °C and 20.2 °C, respectively (https://www.ncei.noaa.gov/access/us-climate-normals/).

TREATMENTS, DATA COLLECTION, AND DATA SUMMARY

Six stands ranging in size between 4.6 and 14.6 ha were identified in the Roses Creek (RC) area (four stands) and Miller Mountain (MM) area (two stands). The stands were all even-aged, mature (>80 years) white pine (*P. strobus* L.)/ upland hardwood forest types with white oak site index (base-age 50) values ranging from 17.7 to 20.1 m.

Between March of 2013 and August of 2014 all six stands were regenerated through a shelterwood with reserves harvest. Post-harvest residual basal area at the MM and RC sites averaged 4.4 and 3.1 m^2/ha, respectively. Reserve trees were dispersed relatively evenly throughout the stands. Merchantable white pine, scarlet oak, Virginia pine (*P. virginiana* Mill.), and black oak were harvested, while white oak, chestnut oak, shortleaf pine, pitch pine, and hickory (*Carya* Nutt.) were retained as reserves. Site preparation activities were similar to that described in the "fell and burn" approach to regenerate mixed pine-hardwood stands (Waldrop 1997, Waldrop and others 1989). Following harvest, all non-merchantable material between 5.1 and 20.3 cm diameter at breast height (dbh) was felled, and a cut stump herbicide treatment (50 percent triclopyr amine in water) was applied to prevent sprouting of mesophytic species (e.g., red maple, blackgum, sourwood [*Oxydendrum arboreum*], sweetgum). Prescribed fires were conducted 6 to 12 months following harvest in all six stands to prepare the sites for planting.

In March of 2015, the four stands in the RC site were artificially regenerated with shortleaf pine using bareroot

1-0 stock planted on a 4.3-m x 4.3-m spacing (treatment = bareroot). During the same time period, the two stands in the MM site were artificially regenerated with shortleaf pine using containerized 1-0 stock planted on a 6.1-m x 6.1-m spacing (treatment = containerized). Unfortunately, because of the opportunistic nature of this study, we were unable to obtain information related to the type of container used or plug size of containerized seedlings. Seedlings that were severely damaged or displayed excessive dieback were culled during planting. All seedlings were produced in one nursery in North Carolina using the same North Carolina Southern Appalachian seed source identified as "superior" (Seed lot SH-50-1-110-1-09-01). In the winter of 2016, a streamline herbicide release treatment consisting of 17 percent triclopyr ester with 1.5 percent adjuvant mixed in basal oil, was conducted on both sites that targeted single stems and sprout clumps of red maple, yellow-poplar, and other undesirable, mesophytic species.

A 30-m buffer was established between each stand and the surrounding undisturbed forest. Random sampling points were then generated at a rate of two plots per hectare. Within all stands, sampling points were ≥20 m apart. Data were collected at the end of one (YR1) and three growing seasons (YR3) after planting. At each sampling location, one artificially regenerated shortleaf pine seedling was tagged and ground line diameter (cm) was measured and recorded as the average of two measurements using a digital caliper. Height (m) of the artificially regenerated shortleaf pine seedling was also measured and recorded. Using a 0.002 ha plot, all competing woody vegetation <3.8 cm dbh was inventoried by species and size classes. Size classes were based on height and diameter and included: stems <0.6 m, stems ≥0.6 m and <0.9 m, stems ≥0.9 m and <1.4 m, stems ≥1.4 m and <3.8 cm dbh.

Survival (%), average height (m), and average ground line diameter (cm) of the artificially regenerated shortleaf pine seedlings were calculated and compared for each site/planting stock. Regeneration data were divided into species subgroups, and average stems per ha were calculated by species subgroup and size class per site for each sampling period. Species subgroups included oak/hickory (OH), red maple (RM), yellow-poplar (YP), southern yellow pine (shortleaf, which included the one planted shortleaf per plot, pitch, Table Mountain [*P. pungens* Lamb.], and Virginia pine) (SYP), and other (OT).

RESULTS

In YR1, bareroot and containerized shortleaf pine seedlings each had 100-percent survival. Survival remained high, regardless of planting stock, with YR3 survival of containerized and bareroot seedlings averaging 100 percent and 96 percent, respectively.

At the end of the first growing season, height of bareroot seedlings averaged 0.26 m, while height of containerized seedlings averaged 0.28 m. After three growing seasons,

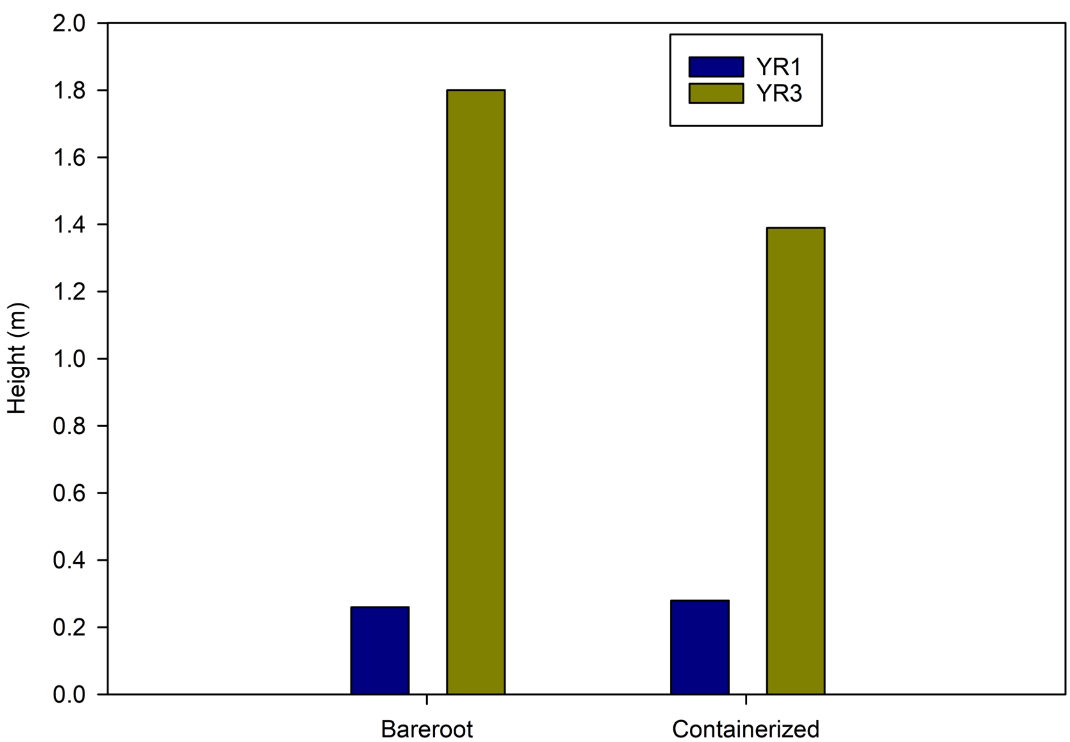

Figure 1—Average height (m) of artificially regenerated shortleaf pine seedlings one (YR1) and three (YR3) growing seasons post-establishment.

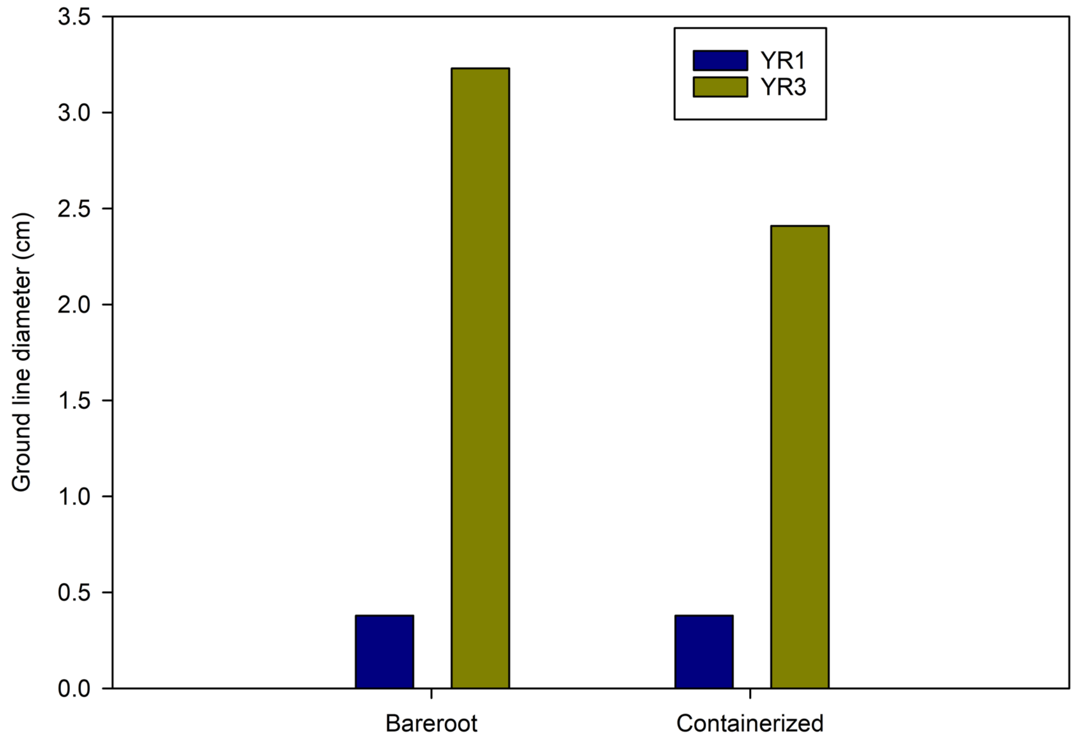

Figure 2—Average ground line diameter (cm) of artificially regenerated shortleaf pine seedlings one (YR1) and three (YR3) growing seasons post-establishment.

height increased to an average 1.80 m and 1.39 m for bareroot and containerized seedlings, respectively (fig. 1). In YR1, ground line diameter of both the bareroot and containerized seedlings averaged 0.38 cm (fig. 2). By YR3, differences in ground line diameter between the planting stocks were observed, with bareroot seedlings averaging 3.23 cm and containerized seedlings averaging 2.41 cm.

Competing woody vegetation, which included both hardwood and conifer species, was diverse and abundant at both the MM and RC sites. After one growing season, woody competition at both sites was dominated by stems <0.6 m (fig. 3), with few stems of any species in the largest two size classes. Although OH and SYP were abundant in the smallest size class (average OH and SYP across the two sites was 1,105

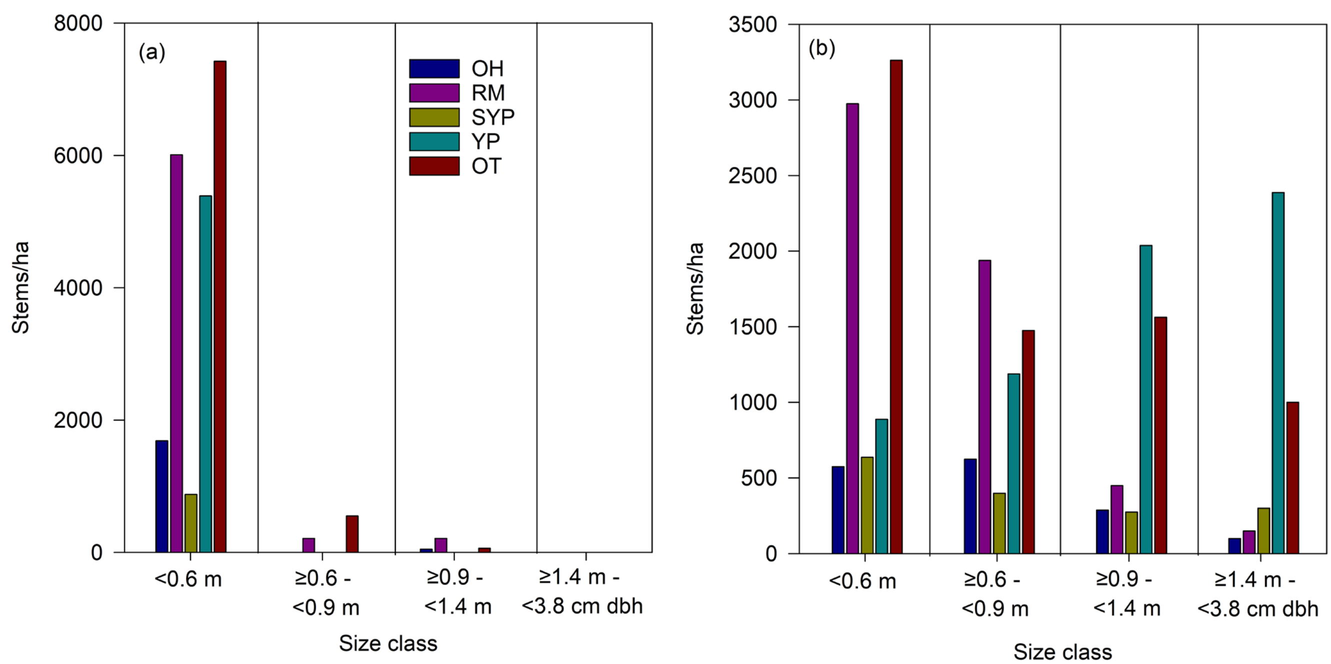

Figure 3—Density (stems/ha) by species group and size class of the competing woody vegetation <3.8 cm dbh (a) one (YR1) and (b) three (YR3) growing seasons post-establishment in the MM (containerized) site. OH=oak/hickory, RM=red maple, SYP=southern yellow pine, YP=yellow-poplar, OT=other.

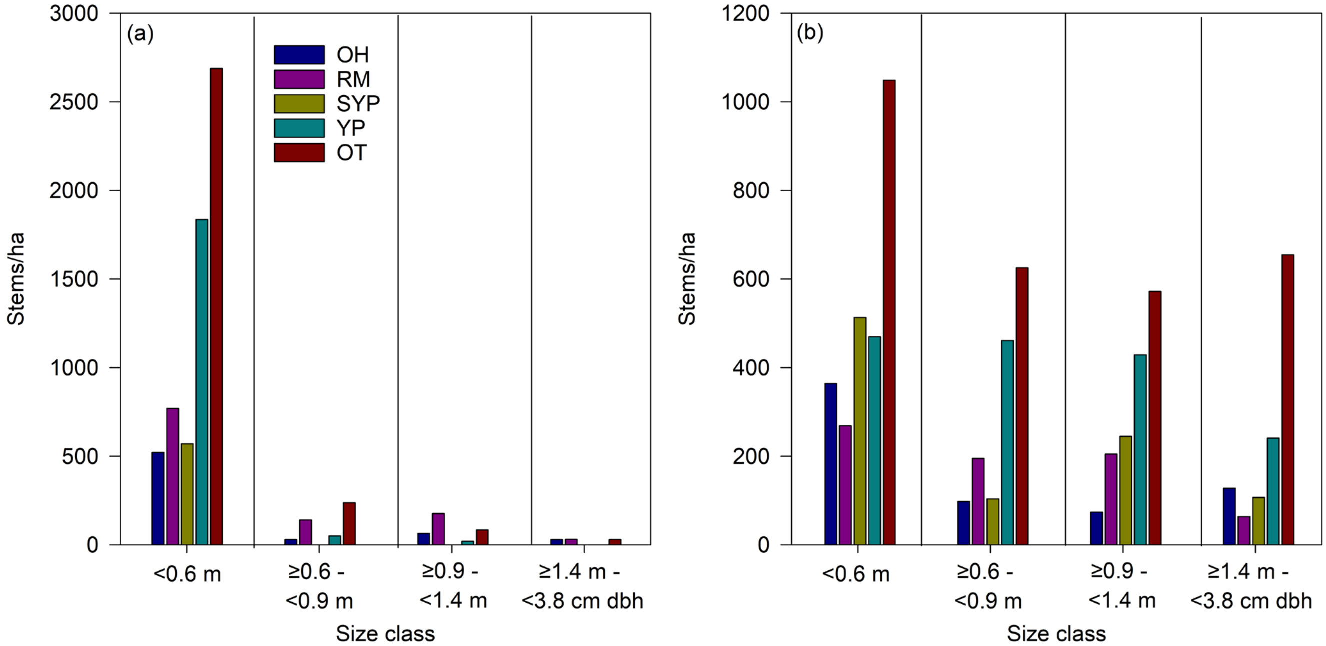

Figure 4—Density (stems/ha) by species group and size class of the competing woody vegetation <3.8 cm dbh (a) one (YR1) and (b) three (YR3) growing seasons post-establishment in the RC (bareroot) site. OH=oak/hickory, RM=red maple, SYP=southern yellow pine, YP=yellow-poplar, OT=other.

and 723 stems/ha, respectively), their relative abundance was low, as the density of YP, OT, and RM across the two sites exceeded 3,300 stems/ha.

There were substantial changes in the size distribution and composition of competing woody vegetation between YR1 and YR3, with recruitment into the largest two size classes evident in both the MM and RC sites (fig. 4). In the largest size class (stems ≥1.4 and <3.8 cm dbh), which represents the individuals most likely to successfully compete and form the dominant and co-dominant canopy layer at crown closure (Loftis 1990), there was an increase of approximately 100 stems/ha of OH between YR1 and Y3 in both the MM and RC sites. Similarly, there was an increase in the density of SYP stems ≥1.4 and <3.8 cm dbh of 300 and 107 stems/ha in the MM and RC sites, respectively. Although both OH and SYP, desirable species from a pine/oak restoration perspective, increased, less desirable species also increased in the largest seedling size class between YR1 and YR3, including an increase of (on average across the two sites) 91, 1,315, and 812 stems/ha of RM, YP, and OT species, respectively.

DISCUSSION

The level of residual basal area in this study can affect growth of planted shortleaf pine seedlings relative to conditions following a clearcut (Kabrick and others 2015, Schnake and others 2021). However, because residual overstory density was similar between the two sites, it is unlikely a direct factor influencing the response of artificially regenerated shortleaf pine in this case study. Survival of planted shortleaf pine seedlings was high, with 100 percent and 96 percent of containerized and bareroot seedlings surviving through YR3, respectively. The negligible difference in survival between the two planting stocks is in contrast with Schnake and others (2021) who report that survival of containerized seedlings was up to 37 percent greater than bareroot seedlings on dry upland hardwood sites in the Piedmont region of North Carolina.

Although data on seedling size at the time of planting were lacking, both height and ground line diameter of bareroot and containerized seedlings were similar after YR1 (figs. 1 and 2), suggesting any differences at planting were likely minor. By YR3, however, relative to containerized seedlings, bareroot seedlings were, on average, 0.43 m taller and possessed ground line diameters that were, on average, 0.82 cm greater. Reports that detail growth and competitiveness of containerized versus bareroot seedlings are conflicting. For example, our results support the findings of Gwaze and others (2006) who report stem diameter of bareroot seedlings was significantly greater than containerized seedlings after two growing seasons. However, the authors did not report any significant differences in height between the two stock types. On the other hand, Schnake and others (2021) found containerized seedlings with large plugs (plug volume = 113.1 mL) outperformed bareroot seedings, with bareroot seedlings being no taller than containerized seedlings with small (plug volume = 93.4 mL) plugs. It is worth noting that nursery records indicate the bareroot and containerized seedlings utilized in this study were likely from the same seed and nursery as the “large plug” seedlings used by Schnake and others (2021), indicating that, at least in this study area, this particular seed source performs as well as either stock type.

CONCLUSION AND FUTURE MANAGEMENT IMPLICATIONS

The response of undesirable hardwood species to a variety of regeneration methods, including two-aged methods (Miller and others 2006), will hamper restoration success without follow-up treatments (Anup and others 2016). Despite the herbicide release (conducted in 2016), the density of hardwood stems in the largest size class (stems ≥1.4 and <3.8 cm dbh) remained high, with that pool of woody regeneration dominated by species that are not necessarily desirable (e.g., YP, OT) from a mixed pine/oak restoration perspective. Although OH stems were present in the largest size class, relative abundance was low, highlighting the need to conduct silvicultural treatments (chemical or mechanical cleaning or release treatments) that encourage the regeneration and recruitment of both shortleaf pine as well as oak and hickory species. If shortleaf pine seedlings are suppressed beyond 5 to 8 years (Kenefic and others 2021, Lyczak 2019) and oak seedlings beyond 8 years (Weigel and Johnson 2000), mortality significantly increases.

Although release of individual seedlings can be accomplished mechanically or chemically, shortleaf pine/oak forests were historically developed and maintained by a variety of disturbances, including fire (Brose and others 2001). Shortleaf pine is well-adapted to fire, as seedlings and saplings can resprout from a basal crook following topkill (Stewart and others 2016). Similarly, oaks, with their conservative growth strategy, maintain high root:shoot and exhibit hypogeal germination; traits linked to increased resprout ability relative to non-oak species (Brose and others 2014). Using fire to control competition has the benefit of being able to treat large areas with relatively low economic cost (Wade 1989). To reduce the risk of mortality to planted shortleaf, prescribed fire should be withheld during the first 3 years after planting, with low-intensity burns repeated every 5 to 8 years to promote pine recruitment and temporarily reduce hardwood competition (Kenefic and others 2021). However, all hardwoods, including red maple and yellow-poplar and various oak species, can resprout vigorously following fire-induced topkill, with the probability of desirable oaks species (e.g., white oak) sprouting being lower than that of red maple and yellow-poplar (Keyser 2019).

Like oak systems in the Appalachians, efforts to successfully regenerate and restore mixed shortleaf pine/oak stands necessitate the reintroduction of disturbance via silvicultural treatments that include harvesting, site-preparation, chemical or mechanical release treatments, and/or prescribed fire over a long period of time (Guldin 2007, Kenefic and others 2021). Shortleaf pine habitat covers approximately 1,139,595 km^2 and is found as far west as eastern Texas and west up to the eastern seaboard of New Jersey. The ecological complexity associated with the range of shortleaf pine suggests no single prescription will be applicable to the range of conditions in which shortleaf pine is found. Genetics (Gwaze and others 2006), environmental conditions, silvicultural methods, including fire and release treatments, and planting methods (South and others 2012) along with other factors, including competition from faster growing hardwoods, will interact to influence the success of planting shortleaf pine (Gwaze and others 2006, Hallgren and others 1993, South and others 2012) and eventual restoration efforts.

This observational (opportunistic) study lacked an experimental design and quantitative descriptors of shortleaf pine seedlings at the time of planting (e.g., plug size, seedling height, root collar diameter, root:shoot, etc.) which limited our ability to make statistically-based inferences related to the effects of planting stock on growth, development, and competitiveness of planting shortleaf pine. Despite these limitations, the results presented provide basic information that can help refine avenues of future research associated with restoring mixed shortleaf pine/oak forests across the Southern Appalachians.

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