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Restoration of Native Fire-Adapted Southern Pine-Dominated Forest Ecosystems: Diversifying the Tools in the Silvicultural Toolbox

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Projections are that the area of planted stands of southern pines will exceed 50 million ac (20 million hectares) by 2060; most will be managed primarily for timber and fiber production using rotations less than three decades in length. This has been a tremendous silvicultural success. However, weighing against that success is the associated decline of native fire-adapted ecosystems dominated by longleaf pine (*Pinus palustris* L.) and shortleaf pine (*Pinus echinata* Mill.), and the flora and fauna adapted to open woodland habitats. Three elements of silvicultural practice will be needed to recover these ecosystems. First, on sites where longleaf pine or shortleaf pine no longer exist but to which they are adapted, planting will be a primary tool to re-establish those species. Second, the reintroduction of fire in stands and landscapes through prescribed burning will also be important, but will be difficult to integrate into operational management. Third, there are silvicultural opportunities in natural stands with a minor component of either longleaf pine or shortleaf pine by using reproduction cutting or thinning, prescribed burning, and release treatments to bring those species back to dominance. Efforts are under way, especially on National Forest lands, to recover longleaf and shortleaf pine ecosystems.

Keywords: longleaf pine, shortleaf pine, prescribed fire, understocked stands

In the latter part of the 20th century, southern foresters became highly proficient at growing planted stands of southern pines, especially loblolly pine (*Pinus taeda* L.), on short rotations for timber and fiber production. The application of genetic improvement has resulted in planting stock that exhibits enhanced tree volume growth, stem straightness, stem form, and disease resistance (McKeand et al. 2003). Control of annual and perennial vegetation using herbicides, and fertilization to enhance early seedling growth, reduced the length of time from planting to crown closure (Allen et al. 2005). These treatments have more than tripled the productivity of southern pine stands and have enabled reductions in rotation length to 25 years or less (Allen et al. 2005, Fox et al. 2007).

By way of comparison, the last half of the 20th century also had good examples of managing southern pines using natural regeneration on industrial timberlands (Zeide and Sharer 2000, 2001). Management of these mixed loblolly–shortleaf (*Pinus echinata* Mill.) stands on the upper West Gulf Coastal Plain featured the shelterwood method using natural regeneration, mechanical precommerical thinning, prescribed burning, and periodic thinning of pulpwood and sawtimber to maturity using a 45-year rotation. Zeide and Sharer (2001) reported a mean annual increment of 465 bf Doyle/ac (~2.7 m^3/hectare) annually using that method, which is about 2.9 green tons/ac (6.5 T/hectare) annually. But Fox and others (2007) reported that the yield of modern planted stands of loblolly pine using 25-year rotations is on the order of 10 tons/ac (22.4 T/hectare) annually, more than three times the volume growth of those naturally regenerated stands. It is easy to see why landowners, especially industry and investment property owners, would be pleased with these silvicultural options.

As a result, fast-growing planted stands of loblolly pine are now the coin of the realm to meet wood and fiber needs in the South. In 1952, Forest Inventory and Analysis (FIA) survey data reported 2 million acres (809,372 hectares) of planted pine stands (Sheffield and Dickson 1998). Today, the Southern Forest Futures Project (SFFP) forecasts an increase in the area of planted southern pine stands from 37 million ac (15 million hectares) in 2010 to 47–67 million ac (19–27 million hectares) by 2060, under the six different cornerstone futures that were modeled (Huggett et al. 2013).

However, this increase in the area of planted stands has come with an unintended ecological effect—a corresponding decline in the area of native mixed naturally regenerated southern pine stands. In 1952, FIA survey data reported that natural pine stands covered

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Figure 1. Mature even-aged shortleaf pine–hardwood stand in which fire has been excluded for at least 25 years. Ouachita NF, Scott County, Arkansas (photo by James M. Guldin).

72 million acres (29.1 million hectares) (Sheffield and Dixon 1998). SFFP data project that the area of natural pine stands will fall from 31.5 million acres (12.7 million hectares) in 2010 to 13.5–23.9 million ac (5.5–9.7 million hectares) by 2060 under those six cornerstone futures (Huggett et al. 2013)—roughly 25–33 percent of the area they occupied in 1952.

Adding to the significance of this ecological effect is the withdrawal of fire from southern pine ecosystems, which has adversely affected the flora and fauna that rely upon the ecological conditions created by fire (South and Buckner 2003, Van Lear et al. 2005, Hedrick et al. 2007). This has been called the "mesophication" of forests (Nowacki and Abrams 2008), and it contributes to enhanced species diversity through the development of shade-tolerant mesophytic midstory and understory plant species, primarily hardwoods (Figure 1). In other words, not only are mature native fire-adapted southern pine ecosystems on a decline, but management actions that exclude the occurrence of fire have led to ecological changes that alter ecosystem structure and function.

This has led to the loss of mature open pine forests and woodlands, and the flora and fauna that rely upon those habitats, across the South—in longleaf pine ecosystems on the lower Atlantic and lower Gulf Coastal Plain (Van Lear et al. 2005, McIntyre et al. 2018), mixed loblolly–shortleaf pine ecosystems on the upper Atlantic and Gulf Coastal Plains and Piedmont (Bragg 2002, Klepzig et al. 2014), pure and mixed shortleaf pine ecosystems from the Atlantic Piedmont, Appalachians, Cumberland Plateau, and the Ouachita and Ozark Highlands (Guldin and Black 2018), and other minor fire-adapted species and communities in the region including pitch pine (*Pinus rigida* Mill.), Virginia pine (*Pinus virginiana* Mill.), table-mountain pine (*Pinus pungens* Lamb.), and sand pine (*Pinus clausa* [Chapm. ex Engelm.] Vasey ex Sarg.) (Welch and Waldrop 2001, South and Harper 2016).

The extent of the decline in two forest types in particular, longleaf pine and shortleaf pine, has triggered the greatest concern. Prior to European colonization, it is estimated that longleaf pine-dominant forests covered roughly 91 million acres (36.8 million hectares)—77 million acres (31.2 million hectares) of longleaf pine-dominant stands, and an additional 14 million acres (5.7) million hectares) of longleaf pine–oak stands, in the eight coastal states from Virginia to Texas (Little 1971, Frost 1993). As of 2010, current estimates from FIA show that longleaf-dominant stands occupy 4.3 million ac (1.7 million hectares) (Oswalt et al. 2012), a decline of 95 percent in its

Management and Policy Implications

Mature stands of native southern pines managed on long rotations are increasingly underrepresented on the landscape. But using planting to establish stands of southern pines targeted for rotations of eight decades or more is difficult to justify economically. Other values will be important to support that practice, highlighted by creating a habitat for species of flora and fauna that are also of concern. The greatest gains in area through planting longleaf and shortleaf pine are likely to be on public lands where landscape-scale prescribed burning can be operationally implemented, and possibly on large privately owned properties where xeric site conditions and anticipated droughty conditions in the future might warrant planting longleaf and shortleaf pine as an investment alternative to the more mesic loblolly pine. The approach of recovering a minor pine component in mixed stands offers several advantages to planting; it has lower out-of-pocket costs, and might offer a positive and more rapid economic return to the landowner. In addition, with the reintroduction of cyclic prescribed fires, thinning and release in stands with a minor pine component will more quickly restore functional habitat for the species of flora and fauna that are of concern in these ecosystems.

historic area. It appears that there has been no net loss of longleaf pine from 1970 to 2010 (Oswalt et al. 2012, Guldin et al. 2016), although there was a slight decline into the 1990s and a recovery since that time. In essence, most of the loss of longleaf pine forests and woodlands occurred prior to 1970 (Frost 1993).

The story is different with shortleaf pine. Native to 23 states, shortleaf pine is the most widely distributed of the southern pines (Little 1971), but was not as widely dominant as longleaf pine. Estimates are that prior to European colonization, pure and mixed forests of shortleaf pine covered 70–80 million acres (28.3–32.4 million hectares) (Mohr and Roth 1897, Anderson et al. 2016). The epicenter of the species was (and still is) the pure shortleaf pine-dominated stands in the Interior Highlands of Arkansas, Oklahoma, and Missouri. But the species was a prominent element of mixed stands of varying proportions of multiple species of oaks and pines (though rarely pure stands), especially in stands under the influence of fire, from New Jersey to Texas. Today, data suggest that shortleaf pine and pine–oak stands cover roughly 6.1 million ac (2.5 million hectares), a decline of more than 90 percent from its historic range (Oswalt 2015, Anderson et al. 2016). And unlike the case with longleaf pine, shortleaf pine continues to decline in area, having declined by 53 percent since 1980 (Anderson et al. 2016). Eight states—Tennessee, Georgia, Alabama, Mississippi, Louisiana, Texas, Oklahoma, and Arkansas—report a decline in shortleaf pine by more than 400,000 acres (162,000 hectares) from 1980 to the present (Anderson et al. 2016).

Abundant species of flora and fauna are uniquely adapted to these frequent fire-adapted southern pine ecosystems (Walker 1993, Van Lear et al. 2005), and their reduced area and condition have placed many of these species at risk. In the Ozark and Ouachita Highlands, for example, American bison (*Bison bison*) and elk (*Cervus canadensis*) have been largely extirpated from forests and woodlands, species such as northern bobwhite (*Colinus virginianus*), Bachman's sparrow (*Peucaea aestivalis*), and the Diana fritillary butterfly (*Speyeria diana*) have limited distribution, and the red-cockaded woodpecker (*Picoides borealis*) is officially endangered (Hedrick et al. 2007).

This decline in the area and condition of fire-adapted southern pine ecosystems has triggered two restoration efforts in the South. The first is for longleaf pine (McIntyre et al. 2018). In 2007, three Federal entities—the USDA Forest Service, the Department of Defense, and the US Fish and Wildlife Service—brought together roughly 20 public agencies and private organizations to develop America's Longleaf Restoration Initiative (ALRI). The ALRI Rangewide Conservation Plan set the ambitious goal of having 8 million acres (3.2 million hectares) in the longleaf pine forest types by 2025 (ALRI 2009). Three million acres (1.2 million hectares) of that is targeted to be in mature "maintenance condition" that provide overstory and understory plant structure and species composition that meet the habitat requirements of the flora and fauna that characterize longleaf pine ecosystems (Figure 2). Halfway through the timeline established by the ALRI, the pace of restoration lags behind (ALRI 2018). That has triggered energetic efforts southwide to enhance the pace and scale of restoration on public and private lands, highlighted by the "Million-Acre Challenge," a commitment established by the Southern Region of the USDA Forest Service to increase the area of longleaf pine on southern national forests by more than a million acres (400,000 hectares) by 2025 (McIntyre et al. 2018).

Following on the success of the longleaf pine initiative, the Southern Region of the Forest Service established an agreement with the University of Tennessee-Knoxville to develop a Shortleaf Pine Initiative. The Shortleaf Pine Restoration Plan (Anderson et al. 2016) proposes three focal areas to maintain, improve, and restore shortleaf pine forests across the South. The first is in the Interior Highlands (Ouachita and Ozark Mountains) in Arkansas, Oklahoma, and Missouri. Shortleaf pine is the only pine native to this region, and the area today still supports extensive stands dominated by shortleaf pine and shortleaf pine–oak forest types. The West Gulf Coastal Plain ecoregion of Louisiana, Texas, southern Arkansas, and southeastern Oklahoma is a second focal area. The northern part of this region supports mixed stands of loblolly and shortleaf pine, in varying mixture with oaks and hickories. A large proportion of the commercial timberland here has been converted to planted stands, primarily of loblolly pine (Bragg 2002, Klepzig et al. 2014). The southern part of this region adds longleaf pine to the mix of species in pure and mixed stands, and includes thousands of acres of planted slash pine (*Pinus elliottii* L.— which is not native west of the Mississippi River) on sites that had been cutover longleaf pine sites (Mann and Enghardt 1972, Lohrey and Kossuth 1990). The third focal area encompasses the natural range of shortleaf pine east of the Mississippi River. This includes a variety of forest types that include shortleaf pine in the pine barrens of New Jersey, the Piedmont, the Ridge and Valley province, the northern Appalachian Mountain Blue Ridge complex, the southern Appalachian Mountains, the Cumberland Plateau, and the Gulf Coastal Plain (Eyre 1980).

Active management will be a key to maintaining, improving, and restoring both longleaf pine and shortleaf pine forest ecosystems. Three elements seem to be critical. First, there is a need to dramatically expand the establishment of new cohorts of regeneration, whether by artificial or natural means. High on the list of priorities is to bring back pine species on sites to which they are adapted, but currently absent. Second, there is a pressing need to dramatically expand the use of prescribed fire, especially on private lands. Finally, there may be widespread opportunities to become more creative silviculturally in stands that have a minor component of desired pine species that could be brought to dominance through reproduction cutting, or intermediate treatments such as thinning.

Artificial Regeneration in a Restoration Context

The role of planting in the restoration of native southern pine ecosystems is simple to the point of being elementary. A tree species absent from a site to which it is adapted can be reintroduced through artificial regeneration, typically by planting (Wakeley 1954). This was science borne of necessity. The introduction of railroad logging and skidding in the longleaf pine-dominated sites on the lower West Gulf Coastal Plain left denuded treeless landscapes with virtually no residual trees of any size (Wakeley and Barnett 2011). One estimate was that 29 million acres (11.7 million hectares) of land that had once been forested was in need of reforestation (Wahlenberg 1960). The technology for plantation establishment outlined by Wakeley (1954) was exemplified by the Yazoo-Little Tallahatchie (YLT) Flood Prevention Project (Williston 1988). From 1948 to 1985, work under the YLT program planted nearly 836,000 ac (338,000 hectares) with 918 million tree seedlings, mostly loblolly pine, on eroded farmlands in northern Mississippi. It was the largest tree planting program known at the time (Williston 1988).

Figure 2. A well-burned longleaf pine stand that meets the criterion of "maintenance class" defined by ALRI (2009), including cavity trees (white marks) for the red-cockaded woodpecker; on the Kisatchie NF in Vernon Parish, Louisiana (photo by James M. Guldin).

The scale of the YLT project has been dwarfed by the deployment of modern genetic improvement and tree-breeding programs in southern pines (Dorman 1976). Forest Survey data show that plantations (tree-sized planted stands in the southern United States, with trees >1.0 inches [2.54 cm] dbh in the stand) cover 46 million acres (18.6 million hectares) of timberlands in the southern United States (Rosson 2015). Most of the planted stands are loblolly pine (80 percent) or slash pine (15 percent), and most of those stands have timber and fiber production as a primary management goal. Notwithstanding the tremendous accomplishment of the YLT project, from 1997 to 2007 the rate of establishment of genetically improved loblolly pine plantations was approximately 1 million acres (400,000 hectares) annually (Aspinwall et al. 2012).

The opportunities for genetic gain also vary by species. Dramatic improvements in genetic gain have been obtained through several generations of breeding in loblolly and slash pines (McKeand et al. 2003, McKeand et al. 2006). Currently, surveys reveal that 84 percent of loblolly pine plantations are established using open-pollinated (OP) families, about 8 percent from control-mass-pollinated families where both parents are known, and about 2 percent from varietals or clonally produced seedlings where the source is one known superior tree (McKeand et al. 2015). These options respectively carry potential for increasing genetic gain and also increasing seedling cost. Family block planting (Duzan and Williams 1988) is now the operational practice in loblolly pine plantations to take advantage of matching family genetic capabilities to specific sites (McKeand et al. 2008). However, there is still substantial genetic diversity at the landscape scale; a given planting zone for loblolly pine may have as many as 350 OP families and 86 full-cross families represented in planted stands (McKeand et al. 2015). Clearly, foresters managing loblolly pine planted stands have a number of options for selection of genetic material.

Options are more limited for longleaf and shortleaf pines. In longleaf pine, the challenge is the availability of seed sources of suitable genetic quality (Guldin et al. 2016). Southwide, longleaf pine seed orchard capacity as of 2015 was approximately 554 ac (224 hectares) of first-generation seed orchards, 44 ac (17.8 hectares) of second-generation seed orchards, 3 acres (1.2 hectares) of third-generation seed orchards, and 272 ac (110 hectares) of seed production areas. Seed inventory across these sites was recently estimated at approximately 11,250 lb (5,100 kg) of seed (Crane 2015, pers. comm.). A thumbnail sketch of seed production capacity suggests that 12,000 lb (5,443 kg) of seed, at 5,000 seed/lb (11,023 seed/kg) (Bonner and Karrfault 2008), yields 60 million seed. Assuming a 90 percent germination rate, 54 million seedlings planted at 600 seedlings/ac (1,482 seedlings/hectare) produces 90,000 ac (36,400 hectares) of longleaf pine plantations. But data from the ALRI accomplishment reports suggest that about 150,000 ac (60,700 hectares) of longleaf pine are being planted annually (ALRI 2018). The quiet secret of longleaf pine restoration in the South is that seed supplies depend upon on collections from native trees in forested settings, such as agency "seed production areas" or other stands on public or private lands that have phenotypically desirable trees, although of unverified genetic provenance. An example of seed collection from seed production areas occurred in the fall of 2014 on the Sabine National Forest in Texas (Weick et al. 2017). In addition, seed supplies in longleaf pine are also complicated by the infrequency of bumper cone crops (Brockway et al. 2007), which adds to the importance of timely cone collections such as the Sabine NF collection in the fall of 2014 when bumper longleaf cone crops were forecast. Adequate seed supply will be a constraint if the area of planted longleaf pine increases significantly in the future (Guldin et al. 2016).

Shortleaf pine is a different story. According to FIA survey data for stands with trees >1 in. (2.54 cm) dbh, there are 46.7 million ac (18.9 million hectares) of planted stands in the South, and shortleaf pine accounts for less than 1 percent of that total (Rosson 2015, pers. comm.). In areas where shortleaf pine and loblolly pine both occur, landowners interested in growing pines tend to plant loblolly pine, which has a clear advantage over shortleaf pine in terms of available genetic gain as well as growth and yield. Nor has there been a groundswell of interest in planting shortleaf pine as there has been with longleaf pine, probably because scientists and practitioners are still coming to grips with the strategies and tactics needed to restore shortleaf pine, especially in mixed stands east of the Mississippi River.

If efforts to plant shortleaf pine increase, seed supply should be sufficient, but there are several other issues to address. Seed orchard capacity for shortleaf pine is largely in Federal ownership; there are about 500 acres (202 hectares) of first-generation shortleaf pine, 27 ac (11 hectares) of second-generation trees, but no third-generation seed orchards and no shortleaf pine seed production areas (Nelson 2015, pers. comm.). However, the path to get shortleaf pine seed from Forest Service seed orchards for use on non-Federal lands is complicated. Typically the Forest Service will sell surplus seed to state agencies, who can then grow seedlings in state nurseries or re-sell surplus seed to private vendors on the open market.

In contrast to longleaf pine, shortleaf pine cones and seed are small and average 47,000 seed per pound (103,600 seed/kg) (Bonner and Karrfault 2008). Assuming that on the order of 10,000 ac (4,046 hectares) annually are planted, at 600 trees per acre (1,482 trees/hectare), annual demand for shortleaf pine is on the order of 6 million seedlings. This would require less than 150 pounds (68 kg) of seed annually. To put that in perspective, the average yearly demand for loblolly pine is roughly 800 million seedlings (McKeand et al. 2015), which at 18,000 seed per pound (39,680 seed/hectare) (Bonner and Karrfault 2008) requires about 45,000 pounds (20,400 kg) of seed. But in seed orchard operations, shortleaf pine cones are inconveniently persistent in the crown of the parent tree. Shaking trees to release ripe cones, which is effective for loblolly, slash, and longleaf pines, is impractical in shortleaf pine seed orchards. Instead, cones are collected by hand using bucket trucks, or by gathering seed using fabric on the ground below the parent tree.

The question of hybridization among the pines, especially between loblolly and shortleaf pine, has been a topic of keen scientific interest in the past decade (Tauer et al. 2012). Awareness of hybrids among the southern pines dates back 100 years, with observations that hybrids between loblolly pine and longleaf pine, colorfully named "Sonderegger" pine, existed (Chapman 1922). Zobel (1953) described hybrids between loblolly and shortleaf pine, generally caused when loblolly pollen fertilized shortleaf cones. He reported that hybrids were intermediate in physiognomy; vegetatively, the hybrid has longer needles and resembles loblolly pine, whereas cones look more like shortleaf cones. Mergen et al. (1965) reported similar attributes of hybrids, but added that the variation in vegetative attributes was highly variable and depended upon the environment where the hybrids grew. Xu et al. (2008) conducted genetic tests on trees in the Southwide Pine Seed Source Study (established in 1951–52, before widespread planting of loblolly pine was common) and reported higher rates of shortleaf pine hybridization west of the Mississippi River (16.4 percent) versus east of the river (2.4 percent). Stewart et al. (2012) designed a study to compare the genetics of the original surviving loblolly and shortleaf pines in the SPSSS with naturally regenerated loblolly and shortleaf pines less than 10 years old at the locations where the trees in the original SPSSS were selected. They reported an increase in hybridization in loblolly × shortleaf pine to nearly 50 percent, and also an increase in loblolly pine hybrids greater than 25 percent, from the early 1950s to the early 2000s. The authors speculated that the natural processes that maintain the genetic distinctiveness of the two species seem to have become less effective over time. In a related study, hybridization increased when mature shortleaf pines were closer to sources of pollen from planted loblolly pine stands (Stewart et al. 2013).

There is also a question whether hybrid character affects development of the characteristic basal crook in shortleaf pine. Shortleaf is the only one of the four major southern pines that can reliably resprout if top-killed, because of the unique basal crook that is found in seedlings and saplings of the species (Figure 3). The crook, which remains in contact with the soil surface, can protect dormant buds from damage by surface fires (Mattoon 1915, Lilly et al. 2012b). Mattoon (1915) reported that "the majority of standing shortleaf timber examined in various portions of Arkansas was found to be of coppice origin." Loblolly pines do not develop a basal crook, and the crook of the shortleaf × loblolly pine hybrid is intermediate (Lilly et al. 2012a). Stewart et al. (2015) demonstrated that prescribed burning causes complete mortality of loblolly pine seedlings after fire and reduces the percentage of hybrids as well, and Bradley et al. (2016) showed the importance of the crook in resprouting.

Because shortleaf pine seed orchards are all OP, they are increasingly subject to loblolly pollen flight at times when shortleaf cones might be receptive. That leads to the possibility that seedlings grown from seed orchards still might have a proportion of hybrids. One might be tempted to cull seedlings prior to outplanting based on whether they have a crook or not. But there are two constraints to that. One is that when shortleaf pine seedlings are grown in containers, the root system will not be visible without disrupting the soil in the container plug, which defeats the purpose of the containerized approach. Second, in some nursery settings, seedlings are planted densely in nursery beds, which might inhibit the development of a prominent crook (Wakeley 1954, Will et al. 2013). Culling bare-root seedlings based on the lack of a crook would be a wasteful loss of genetically pure shortleaf pine seedlings (Stewart et al. 2017). When planting shortleaf pine seedlings, the root collar should be planted slightly below the groundline rather than exposed above the groundline to protect dormant buds from fire (Bradley et al. 2016), and deeper planting depths may increase seedling survival during drought (South et al. 2012).

Foresters can use existing knowledge from the science of artificial regeneration in general, and specific experience in planting longleaf and shortleaf pine, to establish new stands (Barnett et al. 1986, Brissette and Barnett 1992, Jose et al. 2007, Kabrick et al. 2007, Clabo and Clatterbuck 2017, Kirkman and Jack 2017). However, several decades, arguably, will pass before these new planted stands meet maintenance class conditions that provide the habitat sought by species that inhabit mature open pine forests and woodlands that are underrepresented on the landscape. Even more of a challenge is the capacity to dramatically increase available seed supplies.

Figure 3. Shortleaf pine root structure showing the characteristic basal crook below the root collar. In this example, the crook supported the stub of the top-killed shoot as well as new shoots; the diameter of the crook suggests that it predates all of the currently visible shoots (photo by James M. Guldin).

Additional sources for improved seed are needed for longleaf pine, and investments in larger efforts to harvest shortleaf pine seed from existing seed orchards are also needed.

Prescribed Fire

Longleaf pine, shortleaf pine, and loblolly pine have each developed unique adaptations to prescribed fire (Guldin 2008). The basal crook discussed previously in shortleaf pine protects dormant buds from surface fires, and those buds will then sprout if the seedling has been top-killed. In longleaf pine, terminal buds on larger grass-stage seedlings as early as the middle of the first growing season are protected by the whorl of long secondary needles, and the heat of the flames passes above the bud (Wahlenberg 1946, Grace and Platt 1995). Loblolly pine is generally completely killed if the crown of a seedling or sapling is consumed by fire. But the strategy of loblolly pine with respect to fire is the frequent seed production for which the species is known, bearing adequate or better seed crops 4 years in 5 in some parts of its range (Cain and Shelton 2001). In essence, loblolly responds to fire by dropping a new cohort of seed the first autumn after the fire, onto a site with a fire-prepared seed bed.

Because of the discussions about hybridization between loblolly and shortleaf pine especially, prescribed burning in the first few years after stand establishment is critical to ensure that hybrids are also top-killed, because they will resprout much less effectively than pure shortleaf pine seedlings and saplings that have a basal crook. More than being simply a fire-tolerant species, Will et al. (2013) argue that shortleaf pine is a fire-demanding species. They argue that using prescribed fire at a young age in shortleaf pine stands is essential to kill hybrids, and thereby to maintain the genetic integrity of the pure shortleaf pine genome.

A regeneration strategy that employs prescribed fire at a young age will arrest the incursion of loblolly pine and of loblolly × shortleaf pine hybrids in stands where seed sources of mature loblolly are within seeding or pollinating distance. Initiating prescribed burning early in the life of the new age cohort, no later than the third growing season and ideally in the second growing season, will kill most of the loblolly pine saplings, but longleaf seedlings in the grass stage or just starting height growth will survive, and most of the shortleaf pines saplings either will not be completely top-killed or will resprout (Figure 4). However, it takes a determined silviculturist to prescribe a burn in a planted or naturally regenerated stand less than 3 years old.

Prescribed fires can then continue to be applied on the usual cycle (typically, every three growing seasons for these species), and the new age cohort will continue to develop, eventually escaping the crown-consuming effects of the controlled burn. This cyclic prescribed burning regime repeatedly top-kills encroaching hardwood sprouts, and fosters the development of native understory forbs, grasses, and legumes. By age 30–40, precommercial or commercial thinning in shortleaf pine or longleaf pine poletimber stands can be used to maintain a desired residual basal area. Marking can be done to fine-tune the desired species composition, such as retaining a desired hardwood component, or to remove any residual loblolly pines that might have become apparent. The continued attention to using prescribed fire from the start of a new age cohort through the first commercial thinning sets up the transition for open forests and woodlands in mature poletimber and sawtimber stands of both longleaf and shortleaf pines. This approach may also be a pathway toward enhanced structural diversity in multiaged or uneven-aged stands.

But expanding the application of prescribed fire is not without its challenges. For one thing, prescribed burning is not inexpensive. Region-wide cost data suggest that one prescribed fire costs \$26.63 per acre (\$65.77/hectare) (Maggard and Barlow 2018). The discounted costs of a program of prescribed burning on a 3-year cycle for an 80- to 100-year rotation is a costly investment that may not be feasible for private landowners, especially family forest landowners. On National Forest lands, a portion of the proceeds from timber sales can be reinvested in sale area improvements (including recovery of understory flora using prescribed fire) through provisions of the Knutsen-Vandenberg Act of 1933. The economic issue may partly explain why the conservation of endangered species that depend upon open pine forests or woodlands is most commonly found on Federal or State lands.

In addition, although 50 percent of remaining longleaf pine stands are on public lands, ALRI (2018) reports that 80 percent of the 2017 accomplishments in prescribed burning in longleaf pine ecosystems were on public lands. Burn bosses on public lands have learned over the years that on any given burn day, it takes about the same degree of effort and the same size of burn crew to burn 100

Figure 4. Effects of a February prescribed burn that occurred a week before the image was recorded in a 5-year-old regeneration cohort of a two-aged shortleaf pine shelterwood on the Ouachita NF in Scott County, Arkansas (photo by James M. Guldin).

acres (40 hectares) as it does to burn 1,000 acres (404 hectares). The knowledge of how to safely execute larger prescribed fires on a good burning day has been an important element in the recovery of the red-cockaded woodpecker at the landscape scale on public lands. The challenge is how to translate the successful application of prescribed burning to private lands, where issues such as negative public opinion, proximity to residential development, smoke management, and legal liability constrain its application (Haines et al. 2001, Kobziar et al. 2015).

Management of Stands with a Minor Pine Component

Planting and prescribed burning are not exactly new tools in the toolbox of the silviculturist. Broadening the scale and the frequency of prescribed burning is a critical early step in the restoration of mature fire-adapted pine ecosystems. Reliance upon natural regeneration in circumstances where that is warranted will also be important, especially in existing stands currently dominated by longleaf pine and shortleaf pine. This might evolve into the management of stands with complex structure including multiple species and age classes.

Yet, a broader conceptual approach may have potential in the restoration of shortleaf pine and longleaf pine stands across the region. There are opportunities to manage mixed pine and pine–oak stands that have less than 50 percent of basal area in longleaf and shortleaf pine, and bring those pines to dominance. For longleaf pine, there are 4.1 million acres (1.7 million hectares) represented by FIA survey plots having less than 50 percent of basal area in longleaf pine > 5.0 in. (12.7 cm) dbh, with 1.24 million ac (502,000 hectares) where 20–49 percent of basal area is in longleaf pine (Guldin et al. 2016). Similarly, for shortleaf pine, there are 19.5 million acres (7.9 million hectares) represented by FIA survey plots having at least one shortleaf pine > 5 in. (12.7 cm) dbh in the plot, in about 5 million ac (2 million hectares) of which the basal area for shortleaf pine falls between 20 percent and 50 percent of stand basal area (Rosson 2015, pers. comm.). The silvicultural approach to bring those species to dominance is conceptually straightforward, once the stands are identified:

- use commercial thinning to remove the trees of commercial size that are not longleaf or shortleaf pine (although retaining some species diversity may be appropriate, such as overstory mast-producing hardwoods);
- restore cyclic prescribed burning;
- consider a targeted herbicide application if additional control of sprouting hardwoods is needed;
- if regeneration is desired, rely upon the residual stand to provide it through natural seedfall, supplemented by planting in gaps or underplanting.

By one rule of thumb, depending upon the absolute level of basal area and condition of the trees being retained, the silvicultural approach to stands with a manageable minor pine component is basically the shelterwood method, which works well in both longleaf pine (Croker and Boyer 1975) and shortleaf pine (Lawson 1990, Guldin 2007). If the actual basal area of desired overstory pines is in the range of 30–40 ft^2/ac (7–9 m^2/hectare), the marking would in essence be a seed cut for the shelterwood method (sensu Smith et al. 1997, Helms 1998) where only the longleaf or shortleaf pines are retained. Several years might be needed for crowns of the pines to respond to the seed cut with augmented cone and seed crops, but that would give the silviculturist time to reintroduce cyclic prescribed burns to the stand, eliminate any residual loblolly and/

or slash pine seedlings and saplings, and condition the understory and forest floor to be receptive for either natural regeneration or planted seedlings (Figure 5).

Another perspective supporting the idea of silvicultural interventions in stands with a minor component of longleaf or shortleaf pine comes from work on the rehabilitation of cut-over southern pine stands. The Good and Poor Farm Forestry demonstrations at the Crossett Experimental Forest in south Arkansas showed that understocked loblolly–shortleaf pine stands can be brought to full stocking in two decades (Reynolds 1969, Reynolds and others 1984). In the 1990s, Baker and Shelton (1998a) reported results of a study where second-growth loblolly–shortleaf pine stands were cut back to five levels of poor stocking from 10 to 50 percent, with a corresponding range in residual basal area from 4 ft^2/ac to ft^2/ac (0.9–3.7 m^2/hectare). In 15 years, stands with as little as 5 ft^2/ac (1.1 m^2/hectare) of basal area and 20 percent stocking initially recovered to 60 percent stocking with a basal area of 45 ft^2/ac (10.3 m^2/hectare) in 15 years.

The key to recovery in these cutover stands is the response of intermediate and suppressed residual pines after release. Pines with a 20 percent live crown, good apical dominance, and diameter of 2 in. (5.1 cm) at the base of the live crown responded to release by tripling the width of the live crown and increasing crown volume 11-fold in 15 years (Baker and Shelton 1998b). In these upper West Gulf Coastal Plain studies, hardwoods were removed either through harvest or by girdling with herbicides (Reynolds 1980). Empirical data suggest that 1 square foot (or 1 square meter) of hardwood basal area provides shade equivalent to 2 square feet (or 2 square meters) of pine basal area (Shelton 1997). If hardwoods are retained in stands, managers should account for that. In light of this experience, a stand that contains 20 percent stocking or more in the pine component is a candidate for treatments to restore the pines to dominance.

There are two prominent advantages to the restoration and recovery of stands with a minor component of longleaf or shortleaf pine. The first is that the cost of the treatment is far lower than that of establishing a new planted stand of pines. Ideally, the harvested component of those stands could actually provide a financial return to the landowner, proceeds from which could support followup cultural treatments such as any necessary midstory removal and the initiation or continuation of a cyclic prescribed burning program. The second is that functional habitat for fauna and flora that depend upon open pine woodlands with mature trees as dominant high-forest cover could be recovered within a decade, rather than the three to four decades that might be required in a newly planted stand.

There are challenges in proceeding with a widespread program of rehabilitating stands with a minor component of longleaf or shortleaf pine, foremost being how to locate them in the field. Aerial imagery is well developed and improving constantly, but is still a long way from distinguishing among the four species of southern pines in mixed stands. On public lands, it might be possible to locate stands using records that capture species composition collected during stand exams, compartment prescriptions, or watershed management projects. On private lands, especially family forest lands, such records are much less likely to exist. The best approach is to rely upon foresters and other resource professionals and technicians as they conduct their normal program of fieldwork, and to identify stands where recovery of a minor longleaf or shortleaf pine component might be feasible.

Figure 5. Reproduction cutting in a slash pine-dominated stand with a minor component of longleaf pine on the Conecuh NF in south Alabama. Slash pines were commercially harvested, longleaf pines were retained, and the site was drum-chopped and planted with longleaf pine to establish a new age cohort (photo by James M. Guldin).

Summary

The application of existing silvicultural tactics in new and novel ways is needed to broaden the restoration of mature fire-adapted southern pine ecosystems. On public lands, the "Million-Acre Challenge" set forth by the Southern Region of the USDA Forest Service is a giant leap for the restoration and recovery of longleaf pine ecosystems and the unique habitat values they provide on public lands. If successful, the Challenge will more than double the area of longleaf pine on National Forest lands to 1.85 million acres (750,000 hectares), nearly 25 percent of the ALRI goal of 8 million acres (3.2 million hectares) of restored longleaf pine-dominated stands across the range of the species. A similar initiative is planned to expand the restoration and recovery of shortleaf pine. The success of these efforts to dramatically expand the area of mature fire-adapted longleaf and shortleaf pine ecosystems across southern forest landscapes depends upon an expansion in scale and scope of a few key silvicultural tactics.

First, the rate at which new planted stands of these two pine species are established will have to be accelerated. Second, thinning and reproduction cutting treatments in mixed stands should be creatively applied to promote the dominance of longleaf and shortleaf pine in stands where they currently exist as a minor component. Finally, with the goal of maintaining a 3-year fire return interval in stands and landscapes under these restoration prescriptions, a greatly expanded program of prescribed burning will be needed. On private lands, the cost of plantation establishment is daunting unless cost-share programs can be maintained, and the question of expanded application of prescribed fire is much more difficult on private lands than it is on public lands.

The opportunities provided by formalized initiatives such as America's Longleaf Restoration Initiative and the Shortleaf Pine Initiative have been extraordinarily important in focusing attention on the restoration and recovery of these two iconic species of southern pine. However, the larger question is how to maintain mature fire-dependent southern pine-dominated stands, and the species of flora and fauna that thrive and in many cases are uniquely adapted to the habitat these systems provide. The success that professionals and landowners have in accomplishing this restoration program will contribute in favorable ways to the health, diversity, productivity, and sustainability of southern forest ecosystems.

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