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The Silviculture of Restoration: A Historical Perspective With Contemporary Application

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ABSTRACT

In the southern United States, the turn of the 20th century saw the high-grading of virgin pine stands that left millions of acres of forestland in desperate condition. Some of these southern pine stands now support thriving forests whose patterns and processes resemble those extant before they were cut a century ago, but others do not. The success of this recovery in the southern pinery was based upon three primary elements. First, the silvics of the species had something to do with the success of their restoration; some of the southern pines have inherent ecological attributes that lend themselves to restoration, and others do not. Second, the plasticity of high-graded stands under the artful hand of the silviculturists of the day was instrumental in the recovery, partly because of the trees, and partly because of the silviculturists. Finally, major advances in silvicultural science provided astounding successes, and sometimes profound malpractice, in enabling or inhibiting the recovery. A qualitative and quantitative silvicultural review of that history can help modern silviculturists achieve goals of integrated restoration for multi-resource benefits on public and private lands, both regionally and nationally. Key elements for contemporary silviculturists to consider are:

1) that restoration of process drives restoration of structure;

2) that successful restoration demands that a silviculturist balance the cognitive dissonance between economics and ecology;

3) that some tools that traditionally have been associated with intensive forestry for fiber production can help restoration prescriptions succeed at functionally meaningful ecological scale;

4) that a diversity of silvicultural practices among stands across a landscape is more robust than a uniformity of practice; and

5) that restoration will be easier in some forest types than in others regardless of the silviculturist's efforts.

Keywords: restoration, silviculture, ecology, southern pines, conservation forestry

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INTRODUCTION

During the latter half of the 20th century, timber management was the primary goal of silviculture on public and private lands. Projections in the middle of the last century anticipated society's voracious demands for wood and fiber products, and as a result, foresters on both public and private lands began to develop silvicultural practices of agronomic intensity to meet the silvicultural goal of timber production (Spurr 1979). This was done with extraordinary competence; arguably, the two dominant advances in silviculture in the last half of the 20th century were the development of genetically improved planting stock for conifers and fast-growing hardwoods, and the use of chemical amendments such as herbicides and fertilizers to promote fast growth of the desired species and inhibit the growth of the herbaceous and woody species competing with those species. Furthermore, in an undesirable outcome for the profession, silviculture came to be universally associated with timber management (Guldin and Graham 2007).

A key element to success in using timber management has been the exclusion of extraneous damaging disturbance events from forests being managed for timber production. Key to that has been the control of wildfires, which raged through cutover areas and affected the rehabilitation and recovery of the high-graded stands. Professionals in the early part of the last century were keenly interested in forest protection, and considered wildfire the single greatest threat (e.g., Chapman 1942, Reynolds 1947). After World War II, with the GI Bill promoting college education, the profession of forestry grew rapidly--especially the labor force in professional and technical positions in Federal and State forestry agencies. With this expanded pool of workers, effective fire control finally became possible. And effective it was! The Smokey Bear symbol for prevention of wildfire has become one of the most recognized advertising symbols in the world, and control of fires became, and still is, the rule of the day for Federal and State forestry organizations.

The ability of cutover understocked forest stands in the South to recover was in part the result of extraordinary efforts to implement forest management, with emphasis on fire control and silvicultural interventions to manage what remained—especially during a period such as the Depression in the 1930s when funds were scarce and labor was inexpensive and readily available. For example, the roads, firelanes, and early buildings for the Crossett Experimental Forest in Ashley County, Arkansas, were built by Civil Works Administration field crews in 1934, working largely with hand tools, supported by the Department of Labor (Figure 1).

Figure 1— FS Photo 350876. Caption: "Typical 20-foot Forest Service road constructed with CWA hand labor. Road to be graveled and used for utilization of forest products as well as for protection and administration. Road #4 looking east from intersection of roads #4 and #6." 23 July 1937, Crossett Experimental Forest, Ashley County, Arkansas. (Photo courtesy of U.S. Forest Service, Southern Research Station)

But recovery was also due in part, and perhaps in large part, to the nature of the forest types that had been exploited. The species mixtures that recovered in these cutover stands depended upon several elements. First, some trees too small for commercial harvest survived the earlier cutting.

Second, the understocked conditions of cutover stands provided conditions suitable for new woody plants, either as sprouts, established seedlings and advance growth, or seed blown in by the wind, disseminated by animals, or otherwise brought to the site. Third, if all else failed, a new stand was established by artificial regeneration. Through these efforts, modified by infinite site-specific variations in local conditions, new forests became established and have developed to maturity. Today, across the South, thriving forests exist where cutover high-graded remnants were once common. There is a lesson in this restoration and recovery during the last century from which we silviculturists in the 21st century can learn.

For ecosystems adapted to fire, this recovery of forest condition toward the primary goal of timber production coupled with the control of fires in the woods created conditions resulting in the foremost management challenge in the 21st century—that of restoring fire to systems that are prone to burn. Fire-adapted ecosystems represent a confluence of vegetation attributes, site characteristics, and local climatic conditions resulting in ecological systems that will burn if a fire source is introduced to them. The increased fragmentation of the forested landscape places human society's infrastructural investments in homes, pasture, and communities at risk in a landscape adapted to fire, and forest stands managed in the absence of fire can be damaged or destroyed if fire occurs in an uncontrolled manner.

Coupled with this is the under-representation of two kinds of ecosystems on the landscape:

(1), ecosystems with large and old trees, since so few of them survived the high-grading at the turn of the last century, and

(2), fire-adapted ecosystems in which fire has been a regular component.

This creates management challenges, since many species of flora and fauna that require old burned ecosystems are also underrepresented on the landscape.

Thus, the rise of the 21st century poses a different set of challenges for silviculturists, especially on public lands but also in part on non-industrial private lands and even some industry lands—to restore underrepresented old, fire-adapted ecosystems in a landscape increasingly fragmented in ownership and condition. In the South, the keystone species for this restoration is the red-cockaded woodpecker and management of this species is an important objective on forest lands in the South. Equally important ecologically is the creation of the restored habitat that benefits not only the red-cockaded woodpecker, but also a host of flora and fauna adapted to similar habitat conditions.

The tools to achieve this restoration fall squarely in the realm of silviculture. But the success of the restoration has as much to do with the species being managed as it does with using silviculture to create conditions within which the desired species can develop. Interestingly, tools developed for timber production may be important.

To explore these questions, it may be useful to consider case studies from the southern pinery, and adapt lessons learned there to other ecosystems. A subjective case-study analysis of the silvics and silvicultural conditions of three southern pine forest types may have implications and lessons for current efforts in the silviculture of restoration generally. Why focus on the southern pines? Because southern pine-dominated forests grow rapidly, rotations and cutting cycles are short relative to other forest types in the nation; the southern pinery serves as a crucible for silvicultural innovation and the evolution of silvicultural practices in the woodbasket of the nation.

CASE STUDIES FROM THE SOUTHERN PINES

Virgin pine stands across the South were logged from the 1880s through the 1920s. That harvesting and associated disturbance, especially uncontrolled burning, left millions of acres in cutover condition if not completely denuded of trees. Three forest types were harvested with greatest intensity--the longleaf pine (***Pinus palustris*** Mill.) forests of the lower Gulf Coastal Plain, the mixed loblolly-shortleaf (***P. taeda*** L.-***P. echinata*** Mill.) pine forests of the upper Gulf Coastal Plain, and the pure shortleaf pine forests in the Ouachita and Ozark Mountains.

Stands throughout these regions were high-graded of all standing merchantable sawtimber. Cutting rules were simple—essentially, cut all pine trees to a 15-in stump, which translated to about a 12-inch d.b.h. Pines were not cut if they were culls, or below the merchantable threshold. This was the heyday of railroad logging, and the hardwoods (especially the hard hardwoods such as oaks and hickories) growing in mixture with the pines were often cut for railroad ties, cooperage, box manufacture, or use in chemical distillation. After logging, stands were understocked, with an overstory composition of cull pines and hardwoods, pines below the merchantability threshold, and great piles of logging slash. Fires caused by harvesting activities or by settlers to clear undergrowth to promote grasses for livestock were common in these stands. Few foresters believed that these forests would recover anytime in the foreseeable future.

Yet, some of these southern pine stands now support thriving forests. The recovery and management of the loblolly-shortleaf pine forests of the upper Coastal Plain is an astounding success, with some areas now supporting the South's fourth and fifth forests. Loblolly pine and slash pine (*P. elliottii* Engelm.) have been widely planted across the lower Gulf Coastal Plain, and are a mainstay of industrial timber production across the region. The recovery and management of mountain shortleaf pine has been less effective. Pure shortleaf pine-dominated stands and mixed pine-hardwood stands are widespread and have excellent growth and quality, although the recovery of a minor shortleaf pine component in upland hardwood-dominated stands is subject to debate. But unlike the other pine species in the southern forest landscape, longleaf pine has not recovered. It is now found on just a fraction of the area it occupied a century ago.

Figure 2— Well-stocked longleaf pine stand, Sam Houston Ranger District, National Forests and Grasslands of Texas. (Photo by James M. Guldin)

The difference in restorability or recoverability in the southern pines is a function of a number of interacting elements--the species composition, the silvics of the component species with respect to their ability to regenerate and to respond to release from suppression, the nature of the logging, and the accidental or deliberate treatment that followed. These three southern pine species and the habits they exhibit in their respective forest types offer an opportunity to speculate about the ease or difficulty of restoration, and to ponder the silvics and silvicultural attributes of each species in a subjective discussion of the potential to respond to restoration under silvicultural interventions of varying degrees.

LONGLEAF PINE ON THE LOWER GULF COASTAL PLAIN

The natural range of longleaf pine extends from southeastern Virginia to eastern Texas, and encompasses Coastal Plain, Piedmont, and mountain sites in pure or mixed stands (Boyer 1990). But longleaf is especially associated with lower Gulf Coastal Plain terrain, where it is a dominant species and at one time covered extensive areas in pure stands.

At maturity, longleaf pine stands compare favorably to other southern pines, especially with respect to straightness, quality of lumber, and yield of sawtimber volume (Figure 2). But of the three major southern pines, longleaf pine has fared the worst in the transition from cutover condition to contemporary status. An excellent summary of the conditions associated with longleaf pine harvest is presented in Earley (2004). For vast areas, cutover longleaf pine stands did not recover from high-grading, primarily because of the regeneration biology and dynamics of the species.

The slow initial establishment of longleaf pine and the difficulty associated with obtaining natural regeneration made the species impractical for management by the forest industry, especially for fiber production on short rotations. Similarly, the difficulty in obtaining seed for longleaf resulted in problems associated with widespread artificial regeneration relative to other species. These issues, together with the pressing need to reforest cutover sites in the west Gulf region, led managers to plant or direct-seed slash and loblolly pine across vast areas of cutover longleaf pine sites. As a result, longleaf pine has suffered dramatic reductions in area, from more than 90 million acres of original forest to barely three million acres today (Landers and others 1995). Today, pure stands of longleaf pine are restricted to small areas along the lower Gulf Coastal Plain, and on Federal lands in Texas and Louisiana.

Figure 3— Longleaf pine seedling in the grass stage amid dormant grasses. (Photo by D. Andrew Scott)

Longleaf pine may have existed in cutover areas as seedlings in the grass stage in cutover longleaf pine stands (Farrar, personal communication). Longleaf seedlings are difficult to distinguish from grasses (Figure 3); identification during the growing season essentially requires a taste test to identify the pine by its resinous flavor. The intermittent bumper crops of longleaf pine produce high densities of seedlings in clearly-defined age cohorts, an ecological regeneration dynamic of accumulating seedlings similar to that reported for oaks (Johnson and others 2002). After germination, longleaf seedlings remain in the grass stage and gradually increase in root collar diameter over time, under the influence of disturbance and surface fires. If they survive these influences and develop a sufficiently large root system, the seedlings break out of the grass stage and initiate height growth. Thus, it is possible that cutover areas of longleaf might have contained longleaf seedlings, but that those seedlings failed to develop because of the impacts of logging and foraging by feral hogs.

Restoration of longleaf today will be informed by several repositories of silvicultural knowledge. First, the superb work in development of the shelterwood method to regenerate longleaf pine by Southern Station scientists at the Escambia Experimental Forest in southern Alabama united attention to cone crops, understory vegetation control, and the earliest uses of prescribed fire (Croker and Boyer 1975, Boyer 1979). Keys to the method were retaining overstory trees capable of producing cones, to retain sufficient stocking of acceptable overstory trees to optimize seedfall, and to adequately prepare the site when seedfall was forecast. After germination and establishment, seedlings remained in the grass stage for extended periods of time. Brownspot needle blight (***Mycosphaerella dearnessii*** M.E. Barr) was found to inhibit emergence of longleaf pine seedlings from the grass stage, and fires were used to burn off the infected needles. However, the terminal bud of longleaf pine in the grass stage is resistant to mortality by fire because of the insulating nature of the bud scales and the protective needle whorl on the bud.

Secondly, the challenges of reforestation with longleaf have been met, especially in light of containerized planting stock and site preparation treatments that reduce the length of time longleaf seedlings remain in the grass stage (Barnett 2004). Like all southern pines, longleaf trees that have been suppressed but still retain some degree of apical dominance and suitable crown dimensions can respond to release from competition, even at advanced ages.

However, these excellent silvicultural tools of the trade are not sufficient to restore longleaf stands if longleaf is absent at shelterwood densities or greater in the residual stand. Research in artificial regeneration of longleaf pine has been so successful is in part because it has had to be, in order to effectively develop seedlings that can be competitive and especially that can quickly emerge from the grass stage, thereby enhancing their relative competitive status against competing vegetation.

SHORTLEAF PINE IN THE OUACHITA AND OZARK MOUNTAINS

The natural range of shortleaf pine encompasses 22 states from New York to Texas, second only to eastern white pine in the eastern United States (Little 1971). It is a species of minor and varying occurrence in most of these States, typically found with other pines. But in the Ouachita Mountains of western Arkansas and eastern Oklahoma, and in the Boston Mountains and Springfield Plateau of the Ozark Mountains in northern Arkansas and southern Missouri, shortleaf is the only naturally-occurring pine. Pine-dominated stands were and still are common in the Ouachitas and parts of the Ozarks (Figure 4).

Descriptions of presettlement conditions in the region point to a forest type that was more open than currently found, in terms of both overstory stem density and understory condition, with anecdotal comments that a person could ride a horse through the woods without losing their hat. That speaks to an openness of two kinds--an open understory condition promoting easy access for horses, and an overstory condition where low-hanging branches are uncommon or easily avoided.

The high-grading harvest of the Ouachita shortleaf is described in extraordinary detail in Smith (1986). Harvests progressed from south to north, and were conducted by running railroads along and through the long east-west valleys and ridges that characterize the region. Shortleaf pine stands came back in pure stands on south-facing Ouachita and Ozark hillsides that were initially dominated by pines, but questions persist whether shortleaf pine has returned as a minor and varying component in pine-hardwood and especially hardwood-pine stands in the Ozarks.

By and large, shortleaf pine has something of a mistaken reputation as a seed producer. It was thought to produce adequate or better seed crops on the order of every 3 to 6 years (Lawson 1990). But more recent research suggests that in the Ouachitas, adequate or better seed crops can be obtained from managed stands of shortleaf pine on the order of every other year (Wittwer and others 2003).

However, shortleaf pine has a unique attribute of seedlings relative to other southern pines first noticed by Mattoon in 1915—the seedlings, if top killed by fire, will resprout from a basal crook. The physiology of this phenomenon is not clearly understood. However, if a fire overruns a stand with shortleaf seedlings and saplings, many

Figure 4— Well-stocked shortleaf pine stand in pine-bluestem habitat restoration management area, Poteau RD, Ouachita National Forest, Scott County, Arkansas (Photo by James M. Guldin)

will resprout, and the conditions of fire scarification will promote a seedbed for new seedlings. The argument can be made that many shortleaf pine stands between 80 and 100 years old in the Ouachitas are probably of coppice origin after surface fires.

In current stands, shortleaf pine can tolerate overstocking, though at a cost of crown development. Perhaps one of the reasons why the species was thought to be a poor seed producer was based on examination of overstocked stands containing small-crowned trees in poor condition to produce an abundant cone crop. Open overstory conditions promote bigger crowns and better seedfall, and concurrently a more vigorous understory of understory flora.

Figure 5— Well-stocked uneven-aged loblolly-shortleaf pine stand, Compartment 56--Poor Farm Forestry Forty Demonstration, May 2006. Crossett Experimental Forest, Ashley County, Arkansas (Photo by Benjamin S. Glaze)

Seven decades of fire exclusion, however, in these shortleaf pine stands have had the effect of promoting persistent hardwood rootstocks of oaks and hickories. The silviculture of shortleaf pine-bluestem restoration requires the removal of this hardwood midstory to promote the desired grasses in the understory. To date, mechanical treatments and cyclic burning have not quite been sufficient to eliminate these rootstocks.

LOBLOLLY-SHORTLEAF PINE ON THE UPPER GULF COASTAL PLAIN

Loblolly pine has a broad natural range also, only slightly less broad than shortleaf pine and falling short to the extreme northeast and southwest. Throughout most of this natural range, loblolly and shortleaf pines grow together in highly productive stands (Figure 5), with loblolly dominating some mixtures and shortleaf others. The archetypal county in the US in which to show a diversity of silvicultural practices in this forest type is Ashley County, Arkansas, home to the Crossett EF. Here, both loblolly and shortleaf pine have historical prominence not just for the South, but the natural resource history of the Nation--because the first successful efforts to demonstrate forest sustainability through management of second-growth forests occurred in loblolly-shortleaf pine stands at Crossett, Arkansas and Urania, Louisiana (Chapman 1942).

Awareness of tree growth and the potential for economic management of second-growth stands occurred in this forest type for a simple reason—the growth of these pine stands is rapid, and easy to observe in a short period of time. Data show that well-mature stocked stands of loblolly-shortleaf pine exhibit average annual growth rates per acre of 3 square feet of basal area, 80-100 cubic feet of total merchantable volume, 400 fbm Doyle or 450 fbm Scribner. With such growth rates, high-quality sawtimber can be harvested in 50-60 years under conservative management approaches (Reynolds 1959, Reynolds 1969, Baker and others 1996, Guldin and Baker 1998, Guldin 2002).

Relatively good anecdotal evidence remains about the patterns of harvest in mixed loblolly-shortleaf pine stands of the upper West Gulf Coastal Plain, both from Chapman's work and because of the detailed descriptions of rehabilitation and recovery published from Forest Service research centered on the Crossett EF, which was established in 1935 (Reynolds 1942).

Interestingly, research papers and photo captions of the day refer to mixed second growth "shortleaf-loblolly" pine-hardwood type stands (e.g., Reynolds 1947), which may refer to a plurality of shortleaf pine in mixture with loblolly pine and hardwoods. Conversely, loblolly pine dominates these stands today. The difference may be due to the different regeneration dynamics of these two pines. Shortleaf, a less prolific seed producer than loblolly, resprouts if topkilled by fire as discussed above. But loblolly pines topkilled by fire will not recover. The tactic for loblolly seems to lie in that prolific annual seed crop, which drops adequate or better seedfall 4 years in 5 (Cain and Shelton 2001).

Control of competing vegetation, in this case hardwoods, was an essential element of the successful rehabilitation of cutover loblolly-shortleaf pine stands. Early in the recovery process, hardwoods were cut for chemicalwood (an early biofuel product) and as fuel for steam generation in operating sawmills; later, as herbicides came into common silvicultural use in the 1960s, a decadal herbicide treatment was employed and still is recommended in some silvicultural prescriptions (Guldin and Baker 2002).

The need for control of competing vegetation is especially important in situations where reproduction of desired species is found as seedlings, and they are in competition with other species that are not sought but whose regeneration occurs through sprout origin. In the southern pines, this is a dynamic between pine seedlings and hardwood sprouts, which enables the effective application of herbicides that control the hardwoods with minimal effect on the pines. But rather than consider this as a 'kill the hardwoods to release the pines' question, it is more properly seen in strict silvicultural semantics (though admittedly not by the public) as a 'kill the sprouts to release the seedlings' prescription.

Finally, one critical link in the ability of loblolly to recover from understocked cutover conditions was the ability of small suppressed trees with small crowns to respond to release from suppression, even at advanced ages. Standards developed at the Crossett EF suggest that a suppressed loblolly pine tree with a 20 percent live crown ratio, good apical dominance, and a diameter outside bark of 2 inches or greater at the base of the live crown can respond to release, and eventually develop into a codominant crown position (Baker and Shelton 1998).

COMMON THREADS IN THE RECOVERY OF THE SOUTHERN PINES

These three southern pine forest types have little that unites their successful recovery from high-grading at the turn of the last century, because the recovery varied tremendously from one forest type to the next. By and large, Coastal Plain loblolly-shortleaf pine stands fared the best, followed by pure shortleaf pine stands in the Ouachitas and

Table 1— A subjective assessment of the common silvical and silvicultural attributes that must be considered in the restoration of three major southern pine forest types.

Forest type	Frequency of seedfall	Seedling development without fire	Stem density after harvest, 1910-1930	Planting success in 1960?	Planting success today?
Longleaf pine, lower West Gulf Coastal Plain	Fewer than one crop per decade	Poor	Low	Poor	Good
Shortleaf pine, Ouachita-Ozark Highlands	Three crops per decade	Fair	Moderate	Fair	Good
Loblolly-shortleaf pine, upper West Gulf Coastal Plain	Eight crops per decade	Excellent	Moderate to high	Excellent	Excellent

Ozarks, with the poorest recovery found in the longleaf pine forest type in the lower Coastal Plain. It's possible to speculate about several reasons for this related to both silvics and silviculture (Table 1).

The most obvious factor is the frequency of seedfall, with recovery falling along the scalar of seedfall frequency. But there is probably a related effect with respect to fire exclusion. Because loblolly pine, the species with the most frequent seedfall, also has seedlings and saplings most at risk of mortality if topkilled by fire, the coincident effect of fire suppression with prolific seedfall had something to do with its successful recovery. Shortleaf pine, as Mattoon (1915) observed, had seedlings present as advanced growth and an ability to resprout if topkilled, as an adaptive trait to survive the frequent surface fires. As high-grading ended and unchecked fires were controlled, advance-growth shortleaf pine saplings may simply have responded to release, especially in pine-dominated stands. The last disturbance may also have hit shortleaf during a good seed year for the species. It's also easy to see why mixed hardwood-pine stands may be absent on the landscape today—with less fire, and fewer pines as advance growth, there would be less opportunity for pines to develop into the overstory if hardwoods dominate the site.

With longleaf, the story of seedfall is more complicated. The grass stage of longleaf is an adaptive strategy for frequent surface fires, but it renders the species difficult to see. In addition, intense fires will kill longleaf seedlings. It is likely that the heavier cut in longleaf stands relative to the other southern pines resulted in considerably more scarification, and seedfall would have been just about non-existent from the few poor-crowned longleaf residuals after harvest. When fire was removed from the longleaf systems, the probability of longleaf seedlings escaping from the grass stage, especially when infected by brownspot, would have plummeted. Then too, the direct seeding technology that was developed to reforest the deforested longleaf stands relied on slash pine and loblolly pine rather than longleaf, largely because of seed availability (Derr and Mann 1971). Any longleaf seedlings that still persisted were not likely to survive the standard site preparation prescription used with direct seeding--a heavy cultivation treatment, either by disking or harrowing.

A second reason for the variation in recovery by these three southern pines is the degree to which a manageable residual stand was retained, a factor that generally paralleled that of the happenstance regeneration and the stocking of the initially cutover stands. Loblolly's ability to respond to release from suppression undoubtedly helped trees below the diameter limit to respond and eventually to dominate cutover sites. Shortleaf has a similar attribute, and the slower growth rates and smaller sizes of harvested trees in shortleaf probably contributed to retention of a manageable component of shortleaf pine in the mountains of the region after the high-grading occurred. Generally, longleaf pine stands - the most valuable of the three species for lumber at the turn of the last century, and also of great importance to the turpentine industry - were more heavily cut than stands in the other forest types, making recovery all the more difficult.

Finally, if a species cannot regenerate itself in desirable amounts relative to both quantity and distribution, planting will be required to obtain acceptable regeneration. The historical success of planting in these three southern pines is also correlated with recovery from high-grading. Loblolly pine was and is the easiest of the three to plant, and the rise of industrial forestry in the South relates directly to industry's proficiency in planting loblolly and to the success of the genetic improvement program over the 20th century for that species. Shortleaf seedlings are easy to grow in a manner similar to that of loblolly. But successful planting of shortleaf pine is limited by the rocky soils found in Ouachitas and Ozarks, where it is nearly impossible to insert a dibble into the ground. Planting success in shortleaf pine increased dramatically in the latter part of the 20th century with advances in site preparation practices, especially ripping to create a microeroded furrow into which seedlings could be planted; first-year survival improved quickly thereafter (Walker 1992). Conversely, technology for planting longleaf seedings has been more difficult to develop, and also required associated advances in site preparation methods so as to get longleaf pines out of the grass stage in a timely manner (Barnett 2004). Widespread application of this recent technology to successfully plant longleaf pine will be a key to the future recovery of the species.

DISCUSSION

The pattern of recovery of forest stands from high-grading at the turn of the 20th century has lessons for silviculturists in the 21st century. Those lessons relate to applying inventive tactics to take advantage of any unique ecological attributes of the species being managed, to practicing restoration of process in a larger rather than smaller landscape, and to adapting tools for widespread industrial reforestation to a restoration context.

Successful restoration is accomplished in one stand at a time. The first step is to secure the establishment and development of the desired species in the stand being managed. If the desired species for restoration are still present on the site, managers can encourage their development to the point of maturity, and apply reproduction cutting methods appropriate for the species being managed.

For example, if the desired species has the advance growth habit, the disturbance used to recreate the restoration (such as prescribed burning) must not kill the seedlings or saplings completely, or else the process of recruitment of advance growth must begin again. But advance growth reproduction dynamics relate closely to development of new shoots from undamaged rootstocks after the shoots have been top-killed by prescribed fire, as is the case with oaks and two of our southern pines. This requires careful attention to the balance between overstory shade and understory development. It is important in to manage overstory stocking to get enough light to the desired advance growth while not releasing competition too much. Generally speaking, the larger the advance growth at the time of regeneration, the greater is the likelihood of success. Irregular shelterwood reproduction cutting methods are ideal in this approach, and have been successfully applied for long periods of time in mixed loblolly-shortleaf pine stands in the upper West Gulf Coastal Plain (Zeide and Sharer 2000).

Operationally, reliance on advance growth is a less risky silvicultural tactic than relying on seedfall. Precise coordination of harvest operations with a bumper seed crop is difficult on Federal lands, given the multi-year timber sale contracts usually provided to logging contractors. Silviculturally, it is better to rely upon advance growth established prior to logging, and then prescribe site preparation or release treatments after the timber sales have been closed to re-establish advance growth as a uniform age cohort across the site. The alternative for natural seedfall is to prepare seedbeds for seedfall after the timber sale is completed, when the next adequate or better seed crop is expected.

Reproduction cutting methods that rely upon advance growth must be initiated well in advance of the seed cut. Advance growth of a desired species should be encouraged through silvicultural interventions as much as 2 decades prior to the reproduction cutting, so as to be in place prior to the establishment of the new stand. In pines, that can often be accomplished using prescribed fire, which acts both to control competing vegetation and to scarify the forest floor so as to promote germination and seedling establishment—a prescription shown to be effective in loblolly, longleaf, and shortleaf pine. Fire must then be excluded until the seedlings are tall enough to survive it, at which time fire can be reintroduced to the restoration prescription.

Second, some measure of overstory density reduction will be required in most restoration prescriptions, especially if stands have developed through the 20th century after a turn-of-the-century high-grading. In intolerant species, opening stands in this way promotes understory development, which places a premium on the implementation of understory treatments that encourage the desired understory species of forbs and grasses rather than a preponderance of woody plants, especially those tolerant of shade. The limits within which an acceptable understory development of desired forbs and grasses can be mated to acceptable levels of woody plant advance growth for eventual use in reproduction cutting requires a certain degree of balance. It also requires that a silviculturist has some confidence that when the time comes, the desired tree species can be developed immediately after a reproduction cutting prescription is implemented.

Thirdly, successful restoration silviculture demands that a silviculturist balance the cognitive dissonance between economics and ecology. If a reduction in overstory density is prescribed, it is certainly to the advantage of the silviculturist to do so using commercial timber sales. Appropriated funds are usually less readily available than trust funds, which are based in timber sale receipts and thus represent a more liquid capital asset. If a silviculturist can use timber sales to liquidate standing volume assets in excess to the need for restoration, monies for sale area improvement can then be collected and applied for restoration purposes through supplemental reforestation and release treatments. The bottom line is that the area that can be restored using timber sale proceeds is often much larger than can be restored with appropriated dollars. For example, suppose a restoration prescription outside a sale area costs $75 per acre to implement. If 3 mbf per acre of volume in excess of restoration needs can be harvested at $250/mbf, $750 per acre will be generated from the timber sale; conservatively, half of that could be applied for restoration prescriptions within that sale area over the next 5 to 10 years. Over a 200-acre project area in a watershed under prescription development, a manager would need $15,000 in appropriated funds to treat an area, or could draw from a pool of $75,000 in the same area from the timber sale proceeds. Applying the timber sale program in a restoration context provides substantially more flexibility in restoring a larger number of acres at less cost to the agency than would be possible using appropriated dollars, as has been shown in the pine-bluestem restoration program on the Ouachita NF (Guldin and others 2004). The key is in defining the meaning and intent of the 'standing volume in excess of restoration' concept.

Fourth, some tools such as artificial regeneration that traditionally have been associated with intensive forestry for fiber production can be important in restoration. But modification of prescriptions and recommendations may be in order. For example, tree planting will be an important tool for forest restoration when a species is absent from the stand being restored, or in species with erratic seed production. But the practice will differ from planting where industry fiber management is a goal. A new world of opportunity opens for forest geneticists in this context, because we do not know whether families selected for rapid height and volume growth in intensively site-prepared stands will be the same families that thrive in partial shade, or where site preparation is less than complete. Then, too, there may be wisdom in variations of tree spacing when planting for restoration objectives so as to create stem patterns other than rows. A planting crew can plant 544 trees per acre on a strict 8 x 10 ft spacing, or by planting trees on a 3-ft to 15-ft spacing provided that the spacing variation is calibrated to hit the mean.

Fifth, no silvicultural practice should be arbitrarily excluded from the tools in the toolbox of restoration. One tool more cussed than discussed in the 21st century is the use of herbicides, largely because of public distaste for the practice. However, in the southern pinery, herbicides are extremely effective in controlling competing vegetation, especially as a tool to kill sprouting hardwoods competing with pine seedlings or saplings. Midstory hardwoods that became established after the onset of effective fire control may not be desired in the restored stand, and are very difficult to remove without herbicides. Similarly, herbicides may be the only effective way to control invasive exotics such as kudzu and cogon grass that have invaded sites intended for restoration. Silviculturists must justify the use of herbicides for restoration based on achieving the ecological goals the restoration is designed to achieve—and even then, there might be considerable public opposition to the practice. However, in many instances, herbicides will be the single most effective and least costly treatment to control unwanted vegetation. This or any other practice should not be ruled out in advance of silvicultural planning.

However, restoring one stand does not restore the functional ecosystem attributes that transcend the scale of an individual stand. Restoration of ecosystems connotes a scale larger than a single stand, and thus the silviculture of restoration will require prescribing silvicultural treatments concurrently in many stands toward a common ecological goal. This requires that silviculturists expand their view from the traditional stand to the appropriate functional ecological scale. The resulting system of prescriptions for stands within the landscape should become, ecologically speaking, more than the sum of the stand-level prescriptions.

In this context, it is likely that diverse silvicultural practices among stands across a landscape will be more robust than a single textbook prescription. Thirty years ago in Region 8, reproduction cutting decisions invariably prescribed clearcutting and planting, which met important objectives of timber production and creation of early seral conditions, but generally did so in 30- to 40-acre blocks on the landscape. A greater diversity in size and intensity of early seral condition might have been obtained using a diverse even-aged and uneven-aged reproduction cutting methods, not just clearcutting, and through operations in stands of varied area. Similarly, contemporary silviculturists should resist the urge to employ a single restoration prescription, lest the restored conditions become too uniform and fail to reflect the range of natural variability that would be desirable in restored conditions.

Finally, restoration will be easier in some forest types than in others despite the silviculturist's best efforts. The key is the ease with which regeneration of the desired species can become established and encouraged to develop. Some species such as loblolly pine could be restored by taking advantage of that bumper seedfall four years in five, with minimal capital investment. Others such as longleaf will require widespread reforestation using artificial regeneration, with large capital investment to ensure survival. Silviculturists should be increasingly aware of the opportunities for ecological interconnectedness through complementary silvicultural operations in adjacent stands, and through operations on a broad scale rather than a narrow one. The success of restoration in the Ouachita Mountains, for example, is not so much at the scale of a 40-acre stand as at the scale of a 40,000-acre south-facing ridge. This experience exemplifies the silvicultural opportunity of the 21st century—learning how to enable restoration of landscapes through functional arrangements of stands, restored one stand at a time by a silviculturist plying a time-honored craft.

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