UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Publication WSFNR-19-50

December 2019

MANAGING UPLAND LOBLOLLY PINE-HARDWOOD FOREST TYPES FOR GEORGIA LANDOWNERS

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INTRODUCTION

Management of the mixed loblolly pine-hardwood forest type is both a science and an art. Some indefiniteness in the process of managing for these forest types should be expected because of the influence of site history, soil type(s), soil moisture regime(s), current vegetation composition, and choices and timing of management activities all interacting with one another to affect forest structure at maturity (Tomczak 1994). A mixed loblolly pine-hardwood objective offers a flexible and moderately intensive form of forest management compared to more intensive silvicultural activities practiced for pine plantations, but can offer greater forest productivity than a hands-off mixed hardwoods approach. Landowners and practitioners in Georgia should consider loblolly pine-hardwood mixtures if their objectives and the resources on their property are amenable to such management.

HISTORICAL AND CURRENT EXTENTS OF MIXED PINE-HARDWOOD FOREST TYPES IN GEORGIA

OVERVIEW

Upland loblolly pine-hardwood forest types have historically occurred throughout all five physiographic regions of Georgia including the Appalachian Plateau, Ridge and Valley, Blue Ridge Mountains, Piedmont, and Coastal Plain physiographic regions. Loblolly pine-hardwood mixtures with different hardwood species compositions occur in the Coastal Plain physiographic province and will not be discussed here. According to the U.S. Forest Service, Forest Inventory and Analysis (FIA) data, pine-oak or pine-hardwood mixtures contain 25-50 percent pine by stocking with the remainder in mixed hardwoods (Harper et al. 2004). A broad type description for loblolly pine-hardwood mixtures according to the Society of American Forester's Forest Cover Types of the United States and Canada is "loblolly pine-hardwood" (type 82) (Eyre 1980). Hardwood species composition is closely related to the moisture regime of the sites where this forest type occurs (Table 1). Species diversity in this forest type may be high in over a small area (Figure 1). On upland sites, other pine species may also occur with loblolly pine-hardwood mixtures (Table 1).

TABLE 1. COMMON COMPONENT SPECIES OF MIXED LOBLOLLY PINE-HARDWOOD FOREST TYPES.

OAK SPP.	HICKORY SPP.	OTHER HARDWOODS	PINE SPP.
Southern Red *(Quercus falcata)*	Shagbark *(Carya ovata)*	Blackgum *(Nyssa sylvatica)*	Virginia *(Pinus virginiana)*
White *(Q. alba)*	Mockernut *(C. tomentosa)*	Sweetgum *(Liquidambar styraciflua)*	Shortleaf *(P. Eehinata)*
Post *(Q. stellata)*	Sand *(C. pallida)*	Yellow-Poplar *(Liriodendron tulipifera)*	Longleaf *(P. palustris)*
Northern Red *(Q. rubra)*	Pignut *(C. glabra)*	Red Maple *(Acer rubrum)*	
Chestnut *(Q. montana)*		Elms *(Ulmus)* spp.	
Scarlet Oak *(Q. coccinea)*		Ash *(Fraxinus)* spp.	
		Sourwood *(Oxydendron arboreum)*	
		Sassafras *(Sassafras albidum)*	

Figure 1: ***Loblolly pine-hardwood mixtures can have great hardwood species diversity depending on site characteristics. Oaks, hickories and other mast producing species are usually considered the most desirable hardwood species for timber and wildlife management objectives.***

THE LOBLOLLY PINE-HARDWOOD RESOURCE

State forest inventory reports are typically released every 5-12 years by the U.S. Forest Service Forest Inventory and Analysis (FIA) program. The first statewide FIA report for Georgia was published in 1972. Since then, statewide reports have been published every 5-8 years. These reports have shown a general decline in pine-hardwood forest acreage over the past 50 years (Figure 2). The greatest amount of acreage across Georgia in this forest type coincided with the first report in 1972 (4.17 million acres) (Knight and McClure 1974). Following the 1972 report, acreage dropped in 1984, but was followed by a brief increase in 1989 and 1997 (Sheffield and Knight 1984; Sheffield and Johnson 1993; Thompson and Thompson 2002). Since 2000, the area of pine-hardwood forest types has declined to 2.73 million acres (Harper et al. 2009; Brandeis 2015; Brandeis et al. 2016). This area equates to about 11% of the forested acres in Georgia as of 2014. The pine-oak or pine-hardwood forest types designated in these reports include all pine species, but loblolly pine is the dominant pine species in the state in terms of growing stock and is the most likely pine species to be encountered in mixed pine-hardwood forest types (Brandeis 2015).

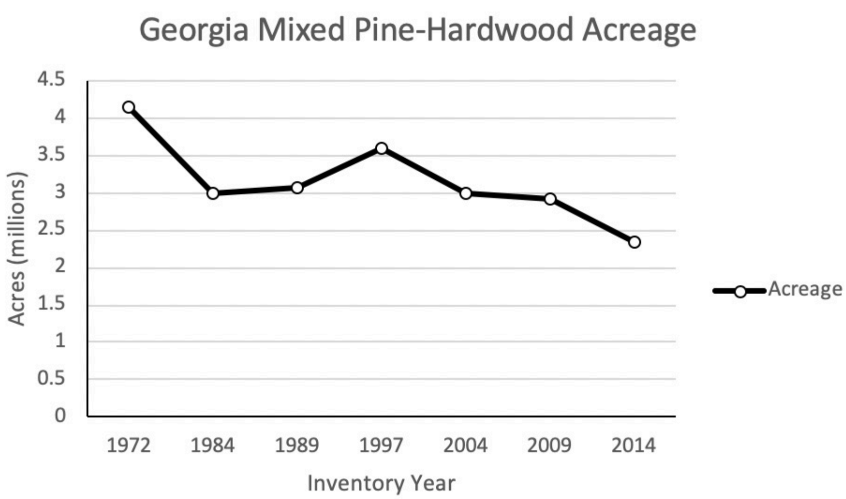


Figure 2: ***USDA Forest Service Forest Inventory and Analysis (FIA) data illustrating mixed pine-oak acreage across Georgia with loblolly pine being the most prevalent pine species (Brandeis 2015).***

The most recent FIA report in 2014 revealed that about 50% of the state's pine-hardwood forests are in "large" diameter stems, which FIA defines as ≥9 in diameter at breast height (DBH) for pines and ≥11 in DBH for hardwoods. Tree sizes in almost 26% of these stands are classified as "medium size" with pines being 5.0-8.9 in DBH and hardwoods 5.0-10.9 in DBH. The remainder (24%) are classified as "small size" forests with stems 1.0-4.9 in DBH for both pines and hardwoods (Figure 3) (Brandeis et al. 2016). Over 85% of the pine-hardwood stands in Georgia originated naturally (i.e. seed, sprout, and advance regeneration), whereas the remainder originated as artificial regeneration (seedlings were planted) (Brandeis et al. 2016). Depending on site history, pine plantations that are neglected or where none or improper site preparation was used often will develop into pine-hardwood mixtures. Non-industrial private landowners own and manage approximately 83% of the state's acreage classified as mixed pine-hardwood. For these landowners, understanding the unique benefits and challenges associated with managing mixed loblolly pine-hardwood forest types may spark an interest in actively managing these stands to meet multiple land-use objectives.

PROS AND CONS OF MANAGING FOR MIXED LOBLOLLY PINE-HARDWOOD STANDS

PROS

Loblolly pine-hardwood mixtures offer several potential benefits to landowners interested in managing existing stands on their property or for those who are interested in establishing new stands. Primary benefits of mixed loblolly pine-hardwood forest types include affordability, forest diversity, and less environmental risk associated with intensive site preparation (e.g. soil erosion on sloped topography) (Tomczak 1994). Possible benefits include (but are not limited to):

- Improved stand resiliency to most insect and pathogen pests due to the diversity of tree species present (e.g. southern pine beetle in the high-risk Piedmont region)
- Usually requires less expensive and intensive site preparation than pure pine plantation establishment
- Multiple management opportunities exist as stands age when a similar ratio of pines to hardwoods exist
- Improved wood quality and stem form due to the different growth rates associated with the variety of species in these stands may result in training tree effects
- Improved wildlife diversity throughout different stand developmental stages.
- Mast production for wildlife
- Diversity of forest products reduces risk associated with uncertain future markets (Figure 4)
- Possibly improved aesthetics for some landowners

CONS

While loblolly-pine-hardwood mixtures offer several benefits, some drawbacks also should be taken into consideration when choosing to manage for this forest type. These cons include but are not limited to:

- Growth rates for pine will be slower than pine planted in pure, intensively managed plantations·
- When establishing mixed loblolly pine-hardwood stands on higher productivity cutover sites, loblolly pine usually must be initially favored and monitored to ensure it is not outcompeted by hardwoods.
- Higher end genetically improved (closed mass pollinated and varietals) loblolly pine seedlings (except those that are rated as having high fusiform rust resistance) typically should not be planted in a mixed stand situation. These seedlings have a lower chance of reaching their growth potential due to the hardwood component.
- Longer rotations than pure loblolly pine plantations are required, yet harvests maybe completed sooner than in mixed hardwood stands
- Management of mixed loblolly pine-hardwood stands is not cookie cutter due to the diversity of species, different silvics of the many species present (e.g. growth rates, shade tolerance, regeneration methods, etc.), and different species' responses to disturbance
- Regenerating balanced (in terms of loblolly pine to hardwood ratios for basal area, trees per acre, etc.) mixed loblolly-pine hardwood stands without inordinately favoring the individual pine or hardwood component can be difficult to accomplish when using natural regeneration sources (Figure 5).
- Fusiform rust (Cronartium quercumm) and redheaded pine sawfly (Neodiprion lecontei) may be more likely to become issues for loblolly pine in mixed pine-hardwood stands due to the presence of hardwoods such as oaks. Oaks act as a component of their life cycle or attract these pests. Plant loblolly pine seedlings with improved fusiform rust resistance.

Figure 3: *Young loblolly pine-hardwood stand located in the Piedmont region of Georgia that would classify either as the "medium" or "small" size classification (Brandeis et al. 2016).*

Figure 4: *Mature loblolly pine-hardwood forest types can offer more timber product options than less diverse forest types, which may be valuable with uncertain future markets. In this stand, sawtimber, pulp, and chip-n-saw products are present for pines and hardwoods.*

ECOLOGY AND STAND DYNAMICS OF MIXED PINE-HARDWOOD STANDS

Mixed pine-hardwood stands often establish and develop with natural regeneration. Some loblolly pine-hardwood forest types, especially in the Piedmont physiographic region, are established as even-age pine stands on abandoned agricultural land. Pines establish via wind-blown seed from nearby mature trees to create pure pine stands that grow and develop until all growing space is utilized. At this point, given no further disturbances, growth stagnation occurs and weaker stems succumb to the increased competition for light, resources, and growing space. This newly available growing space usually has too much overhead shade for pines to regenerate and reach overstory canopy positions, but more shade intermediate and tolerant hardwood species can establish in moderate to low light levels over time eventually creating two-age or uneven-aged mixed pine-hardwood stands. Once hardwoods are introduced to the stand, these mixed pine-hardwood types grow and develop as stratified mixtures where species grow at different rates at different canopy levels. Pine-hardwood stands transition to an uneven-aged form with a diminishing pine component without significant disturbance over time (Langdon 1981, Larson 1992).

Stand replacing disturbances are more likely to cause environmental conditions suitable for natural loblolly pine regeneration than single or even multi-tree canopy gaps (Hart and Grissino-Mayer 2009, Weber et al. 2014). Pine regeneration survival is usually better on lower soil productivity sites after moderate to high severity fires, soil scarification from logging machinery, herbicide applications or combinations of these treatments (Figure 6). Some form of site preparation is usually necessary for pine to compete if hardwoods occupied a site previously. These treatments can expose bare mineral soil and top-kill many of the hardwood sprouts, which allows pine seeds to germinate if a seed source is located nearby. The pine component usually must be favored at establishment if natural hardwood regeneration is relied upon due to fast growth rates of hardwoods with established root systems.

Mixed pine-hardwood forest types are considered mid-successional or transitional in terms of species composition and stage of forest development (Cooper 1989, Halls and Homesley 1966). The mixed pine-hardwood condition cannot be maintained into perpetuity without disturbance. Hardwoods such as white oak and hickory species usually live longer than pines, and often become dominant species in stands that previously contained pine. One exception is on very dry and poor to moderate soil productivity sites, where pines may outlive hardwoods because of their drought tolerance and fire resistance. On most sites, without a stand replacing disturbance mixed pine-hardwood forest types will transition over time to a mixed hardwood species composition (Figure 7).

Loblolly pine as well as several of the most important upland hardwood species such as hickories, yellow-poplar, white oak, southern red oak, and black oak occur most frequently in Georgia on soil series from the Ultisol order. Ultisols are characterized as lower fertility soils at all depths, except the first few inches below the soil surface (topsoil or A horizon). Subsurface horizons are almost exclusively clay textures and soil pH is acidic (Schaetzl and Anderson 2010). Soil series in the Ultisol order frequently occur on the Piedmont (where they often have been eroded due to past land use practices), the Appalachian Plateau, and in the Ridge and Valley physiographic province where fertility typically increases from ridgetop to bottom topographic positions (Segars 1993). Eroded soils (lacking an A horizon), soils with impervious layers (hardpan or plowpan), and soils with a plastic subsoil (soils that can be easily deformed when wet by pressure, but maintain volume and texture characteristics) are typically the least suitable for loblolly pine (Shultz 1997). Commonly favored hardwoods such as oaks and hickories have varying tolerances to these soil conditions, but tend to not respond well to these same characteristics. Site productivity in terms of height growth or site index for codominant or dominant crown position stems of loblolly pine ranges from 60-85 feet at base age 50 years on these sites, but intensive site preparation and improved genetics may increase these values (Baker and Langdon 1990, Shiver 2018). Site index for oak species at age 50 years on sites that may be suitable for loblolly pine-hardwood mixtures will often range from 65-70 feet (Waldrop et al. 1989).

Figure 5: ***Loblolly pine can be an excellent seed producer during some years. An over-abundance of loblolly pine seedlings may occur when relying on natural regeneration.***

Shade tolerance is another important factor to consider with individual species in a mixed pine-hardwood situation. Most valuable timber trees are shade intermediate to shade intolerant. Thus, they require minimal shade levels to reach overstory canopy positions. Valuable timber species such as loblolly pine and yellow-poplar are considered shade intolerant whereas some oak species such as white oak are considered shade intermediate. Mast producing hardwood species can range from shade tolerant (e.g. persimmon and dogwood) to shade intolerant (e.g. black cherry and southern red oak). Being aware of the light requirements of desirable species when regenerating mixed loblolly pine-hardwood stands can help accomplish landowner objectives.

Figure 6: *Young mixed loblolly pine-hardwood stand that developed following a partial harvest in the Piedmont of South Carolina. Photo courtesy of Stephen Peairs, Clemson University.*

Figure 7: *Example of a mixed pine-hardwood stand that is transitioning over to mixed hardwoods without disturbance to promote pine regeneration.*

NATURAL ESTABLISHMENT OF MIXED LOBLOLLY PINE-HARDWOOD FOREST TYPES

OLD FIELD SUCCESSION AND NATURAL REGENERATION SYSTEMS

Mixed loblolly pine-hardwood stands occasionally develop naturally on cleared sites with low to moderate soil productivity such as abandoned agricultural land throughout many areas of the Southeast. During the fall, wind dispersed seed from nearby mature trees enables loblolly pine to colonize former agricultural fields or cutover sites (Bormann 1953). The environmental conditions of these stands allows seedlings to germinate and develop almost exclusively as pure pine with occasional hardwoods such as yellow-poplar or sweetgum and other conifers such as Virginia pine and eastern red cedar mixed with loblolly pine in some locations (Billings 1938, Bormann 1953). Initially the vegetation on these sites is composed of a combination of grasses, herbaceous plants, brambles. These sites frequently also have exposed mineral soil and full sun conditions. On old pastures or fields, when a seed source is nearby, pines will typically appear 3-5 years after abandonment, whereas areas with bare mineral soil such as burned fields or recently tilled or disked fields may contain pine seedlings within a year after abandonment when proper soil conditions coincide with good pine seed crops (Oosting 1942).

Site soil productivity and moisture availability dictates hardwood species rate of establishment and composition with better sites experiencing accelerated establishment rates and more diverse species compositions. Hardwood species such as red bud, sweetgum, dogwood, sourwood, blackgum, and red maple often become common in the understory after about 20 years and retain high stem densities for a few decades without any additional major disturbances (e.g. windstorm, stand-replacing fire, severe ice storm, etc.). At around stand age 20-30, oak seedlings and saplings often become more prevalent in the stand. By age 75, in stands with loblolly pine in the dominant or codominant crown class, oaks and hickories can constitute more than half of the stand's stem density as the overstory pine begins to decline and die (Oosting 1942). The diffuse sunlight cast by pine needles and the increasingly sparse pine trees in the overstory creates the ideal light environment for more shade intermediate oaks and hickories. Species such as redbud, dogwood, and sourwood usually do not grow large enough to emerge from the midstory stratum, whereas red maple and blackgum can be present throughout the midstory and overstory strata. Sweetgum usually fades from the species composition over time but is an intense competitor during the early stages of stand development. Without additional major disturbance to initiate secondary succession, the pine continues to fade over time while oaks and hickories claim overstory dominance (Billings 1938).

Natural regeneration of mixed loblolly pine-hardwood stands can be difficult to accomplish with successful results. Attempts to naturally regenerate these stands should probably only be done on sites that previously had mixed loblolly pine-hardwood stands. Forest floor and canopy disturbances such as grazing, fire, and harvest activities are required for loblolly pine to naturally establish new cohorts from seed. Canopy openings associated with wind events, timber harvest, or tree mortality caused by fire, insects and diseases, or old age can create light conditions suitable for the establishment and growth of loblolly pine. Prescribed fire or soil disturbance caused by logging equipment improves the probability of pine seed germination and some lighter seeded hardwoods (e.g. yellow-poplar) due to bare mineral soil exposure (e.g. Langdon

1981). The seed tree system may be a suitable regeneration method for loblolly pine on sites with a mixed stand history if a loblolly pine seed source is present. Loblolly pine tends to have good seed production years on 3-6 year cycles (Schultz 1997), but this can vary depending on location (especially with more northern latitudes generally having less abundant seed crops). Stand attributes such as basal area and tree ages can also affect seed production. The number of seed trees per acre on a site typically ranges from 10-15 and a release treatment around seed trees should be made two years prior to harvest for seed production increases to coincide with suitable seedbed conditions after harvest (Langdon 1981, Schultz 1997). Hardwood species composition prior to harvesting can have major implications for the next stand. Following disturbances in stands that previously had a hardwood component, sprouting, establishment from seed, and combinations of these regeneration strategies are utilized by different hardwood species to varying degrees. Advanced reproduction (regularly dispersed saplings 4-6 feet tall or greater present in the understory at the time of harvest or a disturbance) is another important regeneration strategy for some hardwoods such as oaks (Loftis 1990). There are many variables to consider with some being very difficult and/or expensive to control when attempting to naturally regenerate mixed loblolly pine-hardwood stands. Due to difficulties with promoting pine regeneration and recruitment into the overstory as well as difficulties with regulating hardwood species composition and stem densities (e.g. McMinn 1989), relying on natural pine and hardwood regeneration is seldom utilized to intentionally regenerate mixed loblolly pine-hardwood stands.

ARTIFICIAL ESTABLISHMENT OF MIXED PINE-HARDWOOD FOREST TYPES

EVEN-AGED MANAGEMENT POSSIBILITIES

1. Clearcut and Regenerate: Clearcut or silvicultural clearcut (cut all stems down to a specific diameter), plant loblolly pine, and rely on natural hardwood regeneration
2. Site Preparation: After clearcutting, utilize site preparation such as prescribed fire or herbicides prior to planting loblolly pine and relying on natural hardwood regeneration can greatly alter species composition at maturity.
3. Release Operations: After planting, herbicide release treatments may improve pine growth/dominance or alter hardwood species composition
4. Planting Pines and Hardwoods: Planting pines and hardwoods on the same site has not been extensively tested and carries risks of failure.

Site productivity and prior vegetation composition are major factors in how loblolly pine-hardwood stands should be artificially established using even-age methods. Low to moderate productivity sites (SI<70 feet at base age 50-years for loblolly pine and oak species) on south, west, and southwest aspects are where loblolly pine-hardwood management can be most successful (Waldrop et al. 1989). Sites that currently contain pine-hardwood mixtures, high graded, or low quality mixed hardwood stands are prime candidates for mixed stand management. The intensity of site preparation and release treatments utilized when establishing mixed stands can determine the abundance of hardwoods and pines at stand maturity (natural and artificially regenerated) (e.g. Harrington and Edwards 1996). A simple silvicultural clearcut harvest followed by pine planting and reliance on natural hardwood regeneration has been utilized as an inexpensive and low impact method to establish mixed loblolly pine-hardwood stands in Georgia with some success on certain sites. Research on two Georgia Piedmont sites with severely eroded Madison soils investigated loblolly pine-hardwood mixture development without conducting any site preparation or release treatments. The results from this study demonstrated that loblolly pine can perform well on similar moderate productivity sites when planted at an 8x10 feet spacing after a silvicultural clearcut (all stems less than two inches diameter are cut) and compete with naturally regenerating hardwoods well enough ten years after harvest to form balanced mixtures of loblolly pine and hardwoods with a significant oak component (Steinbeck and Kuers 1996). It should be noted with this study that clearcuts were completed during the dormant season, and both sites had varying amounts of advance oak regeneration present prior to harvest.

The fell-and-burn site preparation technique followed by planting loblolly pine at wide spacings (10 x 10-20 x 20 feet +) has proven effective for regenerating mixed pine-hardwood stands in multiple regions outside of the Coastal Plain in the Southeast. Past research on moderate to low productivity sites in the Piedmont and Ridge and Valley physiographic regions have shown that clearcut harvesting during the spring or early summer (if possible) followed by a single site preparation burn conducted during September can set back competing hardwoods enough for planted loblolly pine to become established and slow initial hardwood development enough for loblolly pine to survive (Abercrombie Jr. and Sims 1986, Clabo and Clatterbuck 2015, Waldrop et al. 1989, Waldrop 1997). Waldrop (1997) found that that clearcut timing (winter or summer) and site preparation burn timing (winter or summer) had little effect on six-year development of loblolly pine-hardwood mixtures in the Piedmont of South Carolina on former mixed hardwood sites. Loblolly pine was in dominant crown positions after six years while desirable hardwood species such as oaks and hickories were in codominant crown positions (Figure 8). The intensity of site preparation and release treatments after planting can greatly affect the composition of loblolly pine-hardwood stands over time (Clabo and Clatterbuck 2015, Zedaker et al. 1989).

Site preparation and release treatments using herbicides may be necessary on more productive sites where hardwood competition is more intense or when a greater ratio of pine is desired in the final species mix. The brown-and-burn site preparation technique has been proven to greatly increase the proportion of pine as compared to the fell-and-burn method twenty-two years after establishment on Ridge and Valley sites in Tennessee (Table 2) (Clabo and Clatterbuck 2015). The timing of treatments with the fell-and-burn site preparation method are altered slightly for brown-and-burn site preparation. Following harvest, a broadcast herbicide application of imazapyr and glyphosate is completed during mid-summer followed by the prescribed burn during September. Loblolly seedlings are planted during the following winter.

Pine release using herbicides can be used effectively when hardwoods are outcompeting and overtopping planted pines in mixed loblolly pine-hardwood stands. Foliar applications in mixed stands usually involve ground applications using backpack sprayers or sprayers mounted onto ATVs. For foliar treatments, applications should be made in the late summer or fall, and soil active herbicides should not be used due to the possibility of herbicide movement through the soil which can result in uptake and injury to non-target hardwoods. Stem injection or hack-n-squirt with soil and foliar active herbicides may be used for larger (>1-2 inches DBH) undesirable hardwood stems, but care must be taken to avoid spilling or over-applying these herbicides near desirable hardwoods. Zedaker et al. (1989) documented that loblolly pine and hardwood basal area can be altered to meet management objectives using stump herbicide applications (alone and in combination) and basal bark herbicide applications (combination with stump applications) following a silvicultural clearcut (all stems greater than one inch DBH cut) on former mixed hardwood Virginia Piedmont sites. Stump herbicide applications were completed during harvest, and loblolly pine seedlings had completed their first growing season when basal bark release treatments were applied to all hardwoods within 3.3 feet of a planted pine (Zedaker et al. 1989). Pine and hardwood basal area can be adjusted with the intensity of the herbicide application and to an extent with harvest timing (growing vs. dormant season) based on the results from this study (Tables 3 and 4). One drawback with individual stem release treatments is the associated cost. Factors such as location, contractor availability, number of stems per acre to be treated, and stand acreage can affect costs.

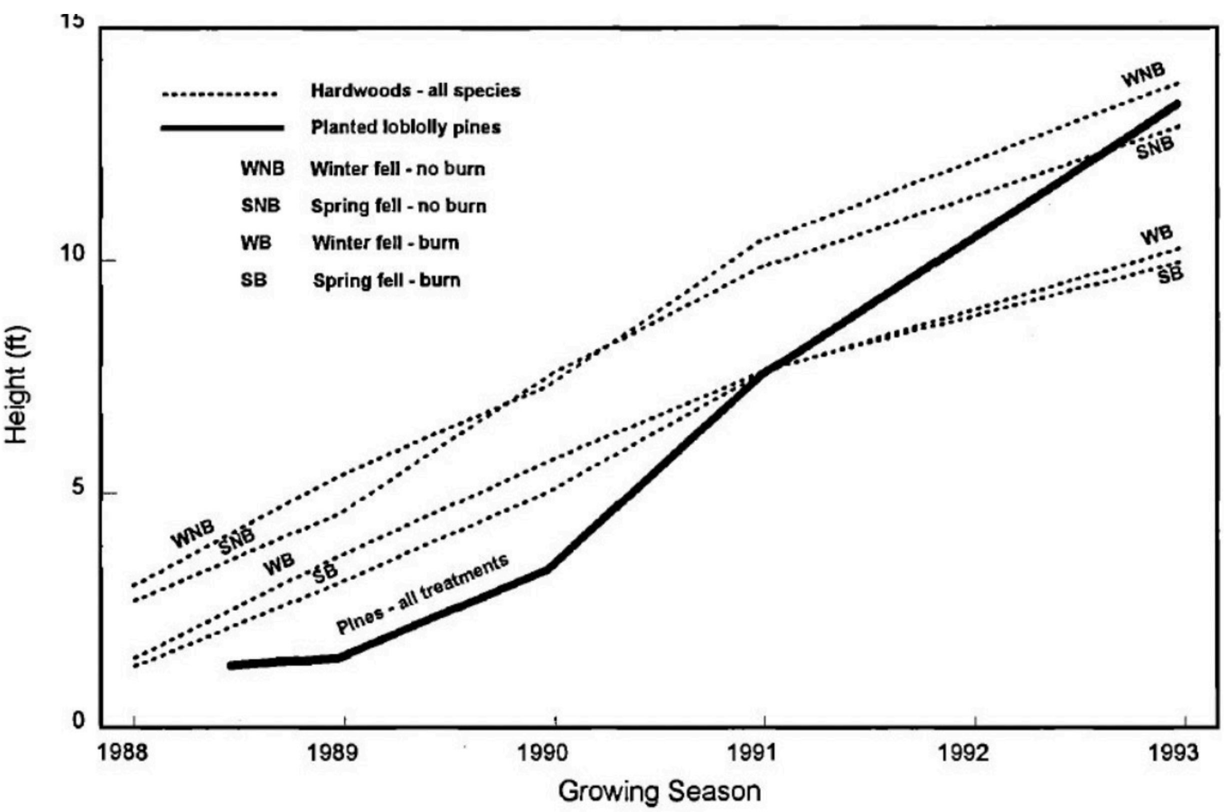


Figure 8: *Relationship of loblolly pine and hardwood growth during the first six years after establishment on a former mixed hardwood Piedmont site (Waldrop 1997).*

Table 2: *Brown-and-burn site preparation can significantly increase the basal area of planted and volunteer pines in loblolly pine-hardwood mixtures (Clabo and Clatterbuck 2015).*

	Commercial Clearcut		Silvicultural clearcut		Fell-and-burn		Brown-and-burn	
	1996	2012	1996	2012	1996	2012	1996	2012
	(ft²/acre)							
Potential overstory hardwood spp.	1.4	90.6	12.3	109.3	0	45.5	1	32.8
Understory species (>2 in dbh)	14.1	5.8	3	8.1	4	3.4	1.6	5.4
Naturally regenerated Virginia pine	0	0	0	0	4.8	44.9	1.6	23.5
Total of all naturally regenerated species	15.5	96.4	15.3	117.4	8.8	93.8	4.2	61.7
Planted pine1	0.3	9.3	0.4	13	1.8	40.1	2.5	48.3
Total basal area	15.8	105.7	15.7	130.4	10.6	134.5	6.7	110
	(% total basal area)							
Naturally regenerated hardwoods and pines	98	91	97	90	83	70	63	56
Planted pine[1]	2	9	3	10	17	30	37	44

[1] Includes both planted loblolly and white pine

Table 3: *Hardwood basal area by harvest season and treatment five years after clearcutting in a Virginia Piedmont mixed loblolly pine-hardwood study (Zedaker et al. 1989). Treatments included: clearcut and natural regeneration only; clearcut and plant loblolly pine; clearcut, cut stump herbicide treatment for hardwoods, and plant loblolly pine; and clearcut, cut stump herbicide treatment for hardwoods, plant loblolly pine, and foliar herbicide release of planted loblolly pine seedlings one year after planting.*

	Harvest Season		
Regeneration treatment	Dormant	Growing	Mean
	(ft²/acre)		
Clearcut	50.8	26.2	38.5
Clearcut, pine	57.1	24.7	40.9
Clearcut, stump treat, pine	15	15.1	15.1
Clearcut, stump treat, pine, release	6.5	5.3	5.9
Mean	32.4	17.8	--

[1] Significance of main effects: harvest p = 0.26, treatment p = 0.005

Table 4: *Loblolly pine basal area by harvest season and treatment five years after clearcutting in a Virginia Piedmont mixed loblolly pine-hardwood study (Zedaker et al. 1989). Treatments included: clearcut and natural regeneration only; clearcut and plant loblolly pine; clearcut, cut stump herbicide treatment for hardwoods, and plant loblolly pine; and clearcut, cut stump herbicide treatment for hardwoods, plant loblolly pine, and foliar herbicide release of planted loblolly pine seedlings one year after planting.*

	Harvest Season		
Regeneration treatment	Dormant	Growing	Mean
	(ft²/acre)		
Clearcut	--	--	--
Clearcut, pine	0.4	3.9	2.1
Clearcut, stump treat, pine	1.3	5.3	3.3
Clearcut, stump treat, pine, release	4.4	11.4	7.9
Mean 2.0	6.9	--	

Significance of main effects: harvest p = 0.02, treatment p = 0.001

Loblolly pine and desirable hardwood species are seldom both planted together to establish mixed stands due to planting and seedling costs, less than optimal growth rates for either loblolly or the hardwood species, as well as difficulty with successfully artificially regenerating hardwoods on droughty, upland sites. Studies documenting results after planting both loblolly pine and hardwoods to establish mixed stands are lacking. One study that was completed on the Cumberland Plateau of Tennessee investigated survival and growth of planted loblolly pine and yellow-poplar along with natural hardwood regeneration after a silvicultural clearcut (all stems greater than 4 inches DBH shear felled) with and without a first year release treatment using herbicide injection on all stems greater than 4.5 feet tall (Kuers 2007). The loblolly pine component performed well and volume was increased almost two-fold by the release treatment versus the no release control, whereas the planted yellow-poplar averaged only 55 percent survival and was outcompeted by natural oak regeneration. Natural oak regeneration comprised over sixty percent of the natural regeneration basal area on this former mixed upland hardwood site (Kuers 2007). This study demonstrates some of the issues with attempting to plant hardwoods (even hardwood species with fast growth rates such as yellow-poplar) in mixed pine-hardwood stands when natural hardwood regeneration is present. Loblolly pine is a plastic, fast growing species on most sites, and planted hardwoods typically cannot maintain growth rates to stay on pace with loblolly pine.

OTHER CONSIDERATIONS WITH ARTIFICIAL ESTABLISHMENT

Selection of planting stock is another important factor for successful artificial establishment of mixed loblolly pine-hardwood mixtures. Containerized or bareroot seedlings are the two types of available loblolly pine nursery stock. Loblolly pine containerized seedlings, though often more expensive and smaller than bareroot seedlings, tend to have greater survival rates and growth for the first few years after planting. This trend is because more of the root system is intact with containerized seedlings after they are lifted from the nursery and less root desiccation occurs on the day of planting due to the soil being present around the roots in the container (Brissette and Barnett 1992). The extra cost of purchasing containerized seedlings is usually recovered with greater seedling survival rates if correct planting procedures and timing are adopted. Some drawbacks of containerized seedlings are the higher seedling and planting costs as well as greater difficulty in handling large quantities of seedlings. Several commercial nurseries in Georgia sell containerized and bareroot planting stock. Work with a professional forester or nursery manager when selecting seedlings. In general, lower-end genetics (e.g. open pollinated seedlings) with parent material from the Physiographic region where planting will occur should be used in mixed loblolly-pine hardwood management situations because of the less intensive silvicultural inputs (i.e. site preparation) and the greater cost of higher-end (mass control pollinated and varietals) genetically improved seedlings. Consider using loblolly pine Performance Rating System sheets (Loblolly Pine PRSTM : Performance Rating System or PRS sheets) to ensure the best fusiform rust and stem straightness ratings are purchased (Figure 9).

Loblolly Pine *PRS*™

Performance Rating System

Family Code: **1-PD015**

PRS™ Ratings — Predicted Family Performance

Productivity Rating **86**

Rust Resistance Grade **A**

Stem Form Grade **A**

The ***PRS***™ ratings indicate that the progeny of family is projected to be:

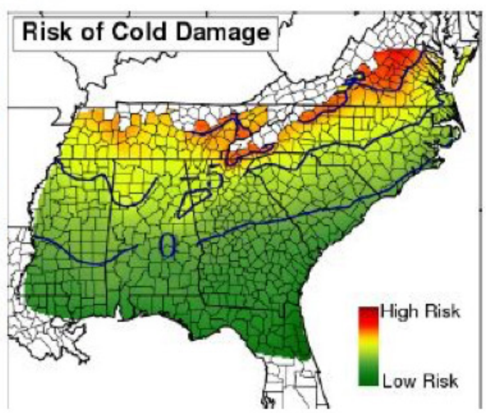
P = 86 → Approximately 86% greater stem volume at age 6 compared to the combined average of local non-improved loblolly pine checklots across the **Piedmont regions of Georgia, the Carolinas, and the Upper Gulf Coastal Plain**.

R = A → **Excellent** for resistance to fusiform rust disease

S = A → **Excellent** for stem straightness

The minimum winter temperature "origin" of Family **1-PD015** is 13.84°F (0° line). Planting in the green shaded areas on the map up to 5°F colder (south of -5° line) has minimal risk of cold damage[1]. Planting in areas that are 5-10°F colder than the origin (between -5° and -10° lines) will increase the risk of cold damage. Areas that are more than 10°F colder than the origin are too cold and planting is not advised (north of -10° line).

Family **1-PD015** has been tested by members of the *NC State University Cooperative Tree Improvement Program.*



[1]These adaptability guidelines were developed by the USDA Forest Service (Schmidtling 2001), Southern Pine Seed Sources, available at: http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs044.pdf

Figure 9: *Loblolly pine performance rating system (PRS) guides developed by the North Carolina State Cooperative Tree Improvement Program can assist with informed decision making when choosing loblolly pine seedlings with specific traits such as improved fusiform rust resistance. Note that this family is rated as having grade "A or Excellent" rust resistance.*

Pine planting spacing is an important consideration when establishing loblolly pine-hardwood mixtures. Grid patterns are standard spatial configurations with pure pine plantations, but spacings within the grid must be made wider than is typically used in pure pine plantations with loblolly pine-hardwood mixtures. Planting the pines at wide spacings allows natural regeneration or planting of hardwood seedlings to occur in the space among the pines. Spacings ranging from 10 x 10 (436 seedlings per acre) to 20 x 20+ (109 seedlings per acre) feet are suitable for loblolly pine because of its fast growth rate and to allow hardwood development in the stand (Clabo and Clatterbuck 2015, Waldrop 1997).

SUMMARY AND CONCLUSIONS

Loblolly pine-hardwood forest types are developmentally complex forests that can be challenging to manage, yet offer landowners many benefits during their different stages of development. Naturally, these forest types occur on lower to moderate soil productivity sites that are well drained and prone to drought. This makes matching management of this forest type to the correct site important for success. Managing for mixed pine-hardwood forest types where a pine component is already present will likely reduce costs and efforts needed for stand establishment. In most instances, stands that develop naturally (even just the hardwood component) will often require some sort of intermediate management to sustain growth rates of crop trees and maintain desirable species composition before the final harvest. Each stand should be assessed individually for any needed site preparation, release, or intermediate treatments to ensure acceptable pine survival and growth rates. In moderate to good productivity (greater than 65 feet site index at base age 25 years for loblolly pine) cutover stands, management of mixed pine-hardwood forest types should lean towards favoring pine species at establishment and early during the rotation. Poorer sites will generally require less intensive site preparation or release treatments in order to ensure a future pine component. The more hands-off approach as compared to intensive pine plantation management and the many possible benefits of mixed pine-hardwood forest types such as increased wildlife diversity and multiple timber products on site at one time could make management of loblolly pine-upland hardwood forest types an attractive option to landowners and practitioners throughout the northern half of Georgia.

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