STATUS OF FUSIFORM RUST INCIDENCE IN SLASH AND LOBLOLLY PINE PLANTATIONS IN THE SOUTHEASTERN UNITED STATES

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Abstract—Southern pine tree improvement programs have been in operation in the southeastern United States since the 1950s. Their goal has been to improve volume growth, tree form, disease resistance, and wood quality in southern pines, particularly slash pine (*Pinus elliottii*) and loblolly pine (*P. taeda*). The disease of focus has been fusiform rust, which is caused by the fungus *Cronartium quercum* f. sp. *fusiforme*. Prior to the 1930s, fusiform rust existed at endemic levels across the region, but following changes in forest management practices during the 1950s and 1960s, the disease increased to epidemic proportions. Since the 1970s, rust-resistant planting stock has been developed and increasingly deployed throughout the southeastern United States. Analysis of data collected by the Forest Inventory and Analysis Program of the Forest Service, U.S. Department of Agriculture showed that current rust incidence is generally higher in slash pine plantations than loblolly pine plantations and that, during the past 30 to 40 years, declines in rust incidence were evident in young (i.e., 5 to 15 years old) planted loblolly pine stands but not in young planted slash pine stands.

INTRODUCTION

Timberland acreage of artificially regenerated[2] (hereafter referred to as "planted") pine stands has increased steadily in the southeastern United States (fig. 1) since 1952 (fig. 2) (Conner and Hartsell 2002). In 2012, there were over 40 million acres of planted pine (*Pinus* spp.) and other softwood timberland in the southeastern United States, 95 percent of which was in the slash pine (*P. elliottii*) and loblolly pine (*P. taeda*) forest types (Miles 2015). Growth rates in these forest types now meet or exceed 300 feet^3 acre^{-1} year^{-1}, more than double the rates of the 1950s (Fox and others 2007, McKeand and others 2003), making them some of the most productive forests in the world (McKeand and others 2003).

The significant increase in pine plantation acreage and productivity since the 1950s is largely due to improvements in silvicultural techniques (e.g., site preparation, fertilization, and weed control); nursery practices; and planting stock (Fox and others 2007). Research cooperatives in Florida, Georgia, North Carolina, and Texas, along with the Resistance Screening Center (RSC) of the Forest Service, U.S. Department of Agriculture in Asheville, NC (Cowling and Young 2013), have been instrumental in improving the volume growth, tree form, disease resistance, and wood quality of slash and loblolly pine planting stock (Allen and others 2005, Schmidt 2003). Li and others (1999) reported that seedlings from first-generation seed orchards produced volume gains of 7 to 12 percent over wild seed, and seedlings from second-generation seed orchards established in the 1980s were projected to produce an additional 14 to 23 percent gain in volume. Third-generation seedlings have been projected to increase productivity even more (Aspinwall and others 2012). The proportion of increased productivity due specifically to increased fusiform rust resistance is substantial. Gains in mean annual increment over a 25-year rotation due to increased resistance to fusiform rust have been estimated at 25 to 30 percent for slash pine and 5 to 7 percent for loblolly pine (Brawner and others 1999, Vergara and others 2007).

Fusiform Rust

Fusiform rust is an endemic disease caused by the pathogen *Cronartium quercum* f. sp. *fusiforme* that requires both pine and oak (*Quercus* spp.) species to complete its life cycle. Infections on pine trees typically result in spindle-shaped galls on the branches and stems (Phelps and Czabator 1978), although galls can be round, oval, or odd-shaped as well. Stem infections that occur before five years of age typically result in tree mortality, whereas infections on older trees create open cankers that continue to enlarge and degrade stem quality and often become points of breakage during storms (Anderson and others 1986). Although fusiform

[2]The Forest Inventory and Analysis (FIA) Program categorizes forest stands into two regeneration classes: natural and artificial. Artificially regenerated stands include stands with distinct evidence of planting or seeding. For simplicity, the term "planted" is used throughout the article to refer to the artificially regenerated stands.

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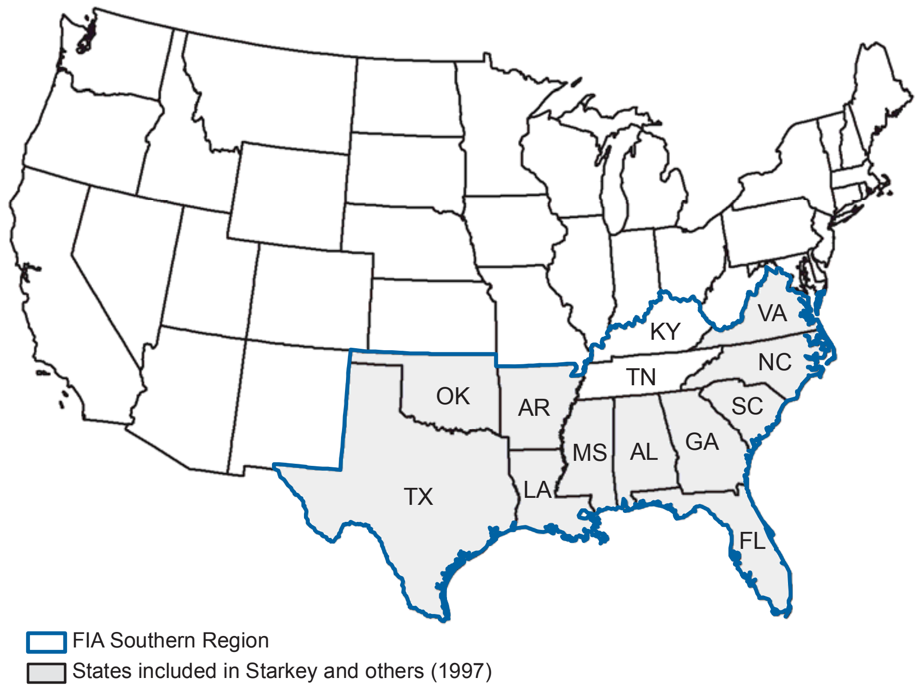

Figure 1—Fusiform rust incidence data from all 13 states of the Forest Inventory and Analysis (FIA) Program Southern Region were included in the report by Randolph and others (2015). The report by Starkey and others (1997) excluded Kentucky and Tennessee.

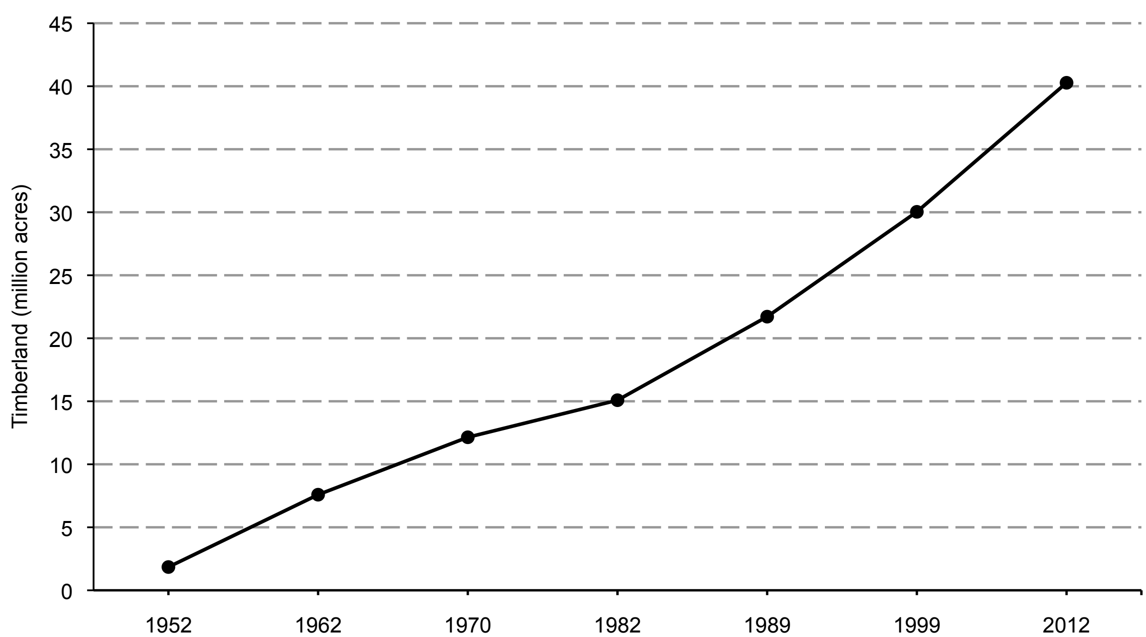

Figure 2—Timberland acreage of artificially regenerated pine (*Pinus* spp.) and other softwood forest types in the southeastern United States, excluding Kentucky, by year. Estimates for 2012 are from the FIA database (Miles 2015). All other estimates are from Table 16.8 in Conner and Hartsell (2002).

rust affects several southern pine species, slash pine and loblolly pine are the most susceptible (Phelps and Czabator 1978).

In the early 1970s, fusiform rust infection exceeded 50 percent in young pine plantations across much of the southeastern United States. Isogram charts of rust incidence in 8- to 12-year-old slash pine and loblolly pine plantations showed a ridge of high rust incidence extending from Louisiana to South Carolina for both species (Squillace 1976). Starkey and others (1997) estimated that fusiform rust infection was ≥50 percent on 8 percent of the 3.8 million slash and loblolly pine timberland acres inventoried by the Forest Service Forest Inventory and Analysis (FIA) Program in Mississippi, North Carolina, South Carolina, and Virginia in the late 1970s. By the early 1990s, ≥50 percent rust incidence was observed on only 1.2 percent of the 8.8 million slash and loblolly pine timberland acres in those same four states. Southwide (fig. 1), however, the proportion of slash pine timberland acreage with ≥10 percent rust incidence showed a slight upward trend over the same time period (Starkey and others 1997).

Objectives

As the fortieth anniversary of the establishment of the RSC approached, and 13 years after the publication by Starkey and others (1997), leaders of the university-industry tree improvement research cooperatives in Florida, North Carolina, and Texas, and the manager of the RSC, organized an information exchange working group meeting with the general theme "Integrating Fusiform Rust Research, Screening, and Breeding" (Cowling and Randolph 2013). During this meeting, several questions were raised concerning the current status of fusiform rust, including (Cowling and Randolph 2013):

1. What is the current status of the fusiform rust epidemic in slash pine and loblolly pine?
2. Has fusiform rust incidence decreased, increased, or remained the same throughout the South over the last 40 years?
3. Have the areas of high rust disease hazard changed over time?

Follow-up discussions led to the development of two papers (Cowling and Randolph 2013, Randolph and others (2015) that capitalized on four decades of FIA fusiform rust incidence data collected across the southeastern United States.

The first paper (Cowling and Randolph 2013) explored the benefits of conducting an updated analysis of the FIA data similar to the one performed by Starkey and others (1997) and included an initial analysis of fusiform rust incidence data collected by FIA between the years 2000 and 2011. During the course of the paper's writing, it was discovered that when the Enhanced FIA Program was introduced in 1999 (Bechtold and Patterson 2005), FIA data collection protocols were revised so that fusiform rust symptoms, i.e., rust galls directly on the main stem or on branches within 12 inches of the stem, would be noted only on trees ≥5 inches diameter at breast height (d.b.h.) rather than ≥1 inch d.b.h. as had been done previously. As a result, it was not possible to make current estimates of timberland area damaged by fusiform rust that would be directly comparable to those reported by Starkey and others (1997). Therefore, to address the three questions listed above, Randolph and others (2015) based their analyses on estimates of percent rust at either the state or the plot level. Results for planted slash and loblolly pine timberland were presented at the 18th Biennial Southern Silvicultural Research Conference (BSSRC) and are summarized in the sections that follow. Readers are referred to Randolph and others (2015) for similar results for natural slash and loblolly pine timberland and for a more detailed discussion overall.

METHODS

Plot-, condition-, and tree-level data from the late 1970s through 2012 were obtained from the FIA database (O'Connell and others 2010) for Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. Only data from timberland plots with the slash pine or loblolly pine forest type and live slash pine and loblolly pine trees ≥5 inches d.b.h. were kept in the data set. Timberland is defined as forest land capable of producing industrial wood in excess of 20 $feet^3$ $acre^{-1}$ $year^{-1}$ and not withdrawn from timber utilization (USDA Forest Service 2006).

Data from the 2010 (Texas), 2011 (Florida, Kentucky, and Tennessee) and 2012 (all other states) FIA inventories were used to estimate the current status of fusiform rust ($\hat{R}_{current}$) in each state by forest type. Likewise, data from the FIA inventories conducted in the late 1970s (Arkansas, Mississippi, North Carolina, South Carolina, and Virginia) or early 1980s (Alabama, Florida, Georgia, Louisiana, Tennessee, and Texas) were used to estimate the past status of fusiform rust ($\hat{R}_{oldest}$) in each state by forest type. The ratio of means estimator (Cochran 1977, Zarnoch and Bechtold 2000) was used to estimate $\hat{R}_{current}$ and $\hat{R}_{oldest}$ as the percentage of live trees (≥5 inches d.b.h.) with symptoms of fusiform rust. The change in rust incidence over time was calculated as the difference ($\hat{R}_{diff}$) between the oldest and most current inventory for each state and forest type. $\hat{R}_{current}$ and $\hat{R}_{oldest}$ were considered significantly different from one another (α=0.05) if the 95 percent confidence interval for $\hat{R}_{diff}$ did not include zero.

In order to map current rust hazard, plot-level percentages of rust incidence (p_i) were calculated for each FIA plot inventoried in the 2010s. Following the methods of Starkey and others (1997), inverse distance weighted interpolation (ESRI® 2010) was applied to the p_i values to create a grid (raster) coverage of rust incidence percentages for each forest type. The resulting grid coverages were classified into categories of low hazard (0 to <10 percent infection), moderate hazard (10 to 30 percent infection), and high hazard (>30 percent infection).

RESULTS AND DISCUSSION

Current Fusiform Rust Incidence

Estimates of current fusiform rust incidence varied by state and forest type. For the slash pine forest type, the percentage of live trees (d.b.h. ≥5 inches) with symptoms of fusiform rust ranged from a low of 6.4 percent in Mississippi to a high of 21.2 percent in Georgia. For the loblolly pine forest type, the percentage of live trees (d.b.h. ≥5 inches) with symptoms of fusiform rust ranged from a low of <1 percent in Kentucky, Oklahoma, Tennessee, and Virginia to a high of 12.7 percent in Georgia. In states for which estimates were made for both forest types, rust incidence was generally higher for the slash pine forest type than for the loblolly pine forest type (fig. 3). This may be due, at least in part, to slash pine's greater susceptibility to fusiform rust infection (Zhao and Kane 2012).

Temporal Changes in Rust Incidence

Estimates of the change in fusiform rust incidence in young (5 to 15 years old) slash and loblolly pine plantations from the late 1970s or early 1980s to the 2010s showed that, in some states, rust incidence in young loblolly pine plantations is lower now than it was previously, but this was not the case for young slash pine plantations. Significant (α=0.05) declines in rust incidence in the loblolly pine forest type were observed in Alabama, Georgia, Louisiana, South Carolina, and Texas (fig. 4). In Virginia, a significant (α=0.05) increase in rust incidence in the loblolly pine forest type from 0.2 percent in 1977 to 2.0 percent in 2012 was observed. For young slash pine plantations, there was a significant (α=0.05) increase in fusiform rust incidence in Florida, whereas rust incidence remained statistically unchanged in Georgia (fig. 5). The reason or reasons for the increase in fusiform rust incidence in planted slash pine in Florida are unclear. Increased genetic gains in tree growth and improved management practices that allow rust-infected slash pine trees to survive longer now than in the past may be contributing factors (Randolph and others 2015).

The extent to which rust reductions in the young planted loblolly pine stands can be attributed directly to the planting of rust-resistant planting stock is not known with certainty because decreases in rust incidence also were observed in naturally regenerated loblolly pine stands (Randolph and others 2015). However, the decreases in fusiform rust incidence in the planted loblolly pine forest types were typically greater in the planted stands than in the natural stands (Randolph and others 2015). Thus, at least a portion of the reduction in rust incidence was likely due to the deployment of rust-resistant planting stock.

Current Rust Hazard

Despite some decreases in fusiform rust incidence over the last 30 to 40 years, rust hazard remains high throughout much of the southeastern United States, especially in areas where the historical range of slash pine and loblolly pine overlap (fig. 6). Rust hazard is highest for the slash pine forest type in Georgia, southeastern Alabama, northern Florida, and an area centered on the border of Texas and Louisiana. For the loblolly pine forest type, high rust hazard is currently concentrated in northern Florida and across the Upper Coastal Plain and Piedmont regions of Alabama, Georgia, and South Carolina. Rust hazard is lowest for loblolly pine along the northern portion of its historical geographical range (fig. 6).

SUMMARY

The current patterns of rust incidence and rust hazard generally reflect what was observed by Squillace (1976) and Starkey and others (1997). Given that *C. quercum* f. sp. *fusiforme* is endemic to the southeastern United States, such patterns are likely to persist. As slash pine and loblolly pine continue to expand through plantation forestry, areas where these species are not historically native and where one or both of them now exist should be monitored closely for evidence of fusiform rust.

Rust incidence is generally higher in slash pine plantations than loblolly pine plantations, and though decreases in fusiform rust incidence were evident over the last 30 to 40 years in young loblolly pine plantations, no declines were observed in young slash pine plantations. Thus, there appears to be an opportunity to improve fusiform rust management in slash pine plantations through either improved planting stock or silvicultural practices, or both.

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LITERATURE CITED

Allen, H.L.; Fox, T.R.; Campbell, R.G. 2005. What is ahead for intensive pine plantation silviculture in the South? Southern Journal of Applied Forestry. 29(2): 62-69.

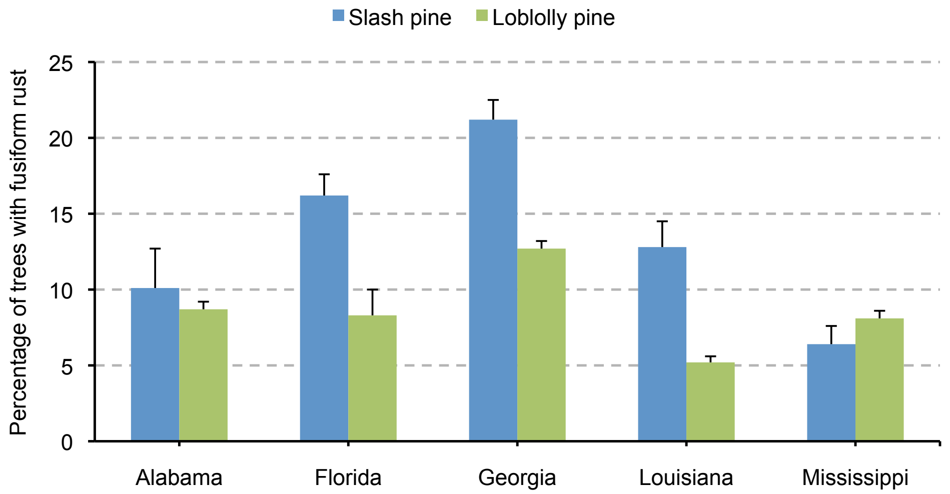

Figure 3—Estimated percentage of live trees (diameter at breast height ≥5 inches) with symptoms of fusiform rust, by state and forest type, for the years 2011 (Florida) and 2012 (all other states). Bars extending from the columns represent one standard error.

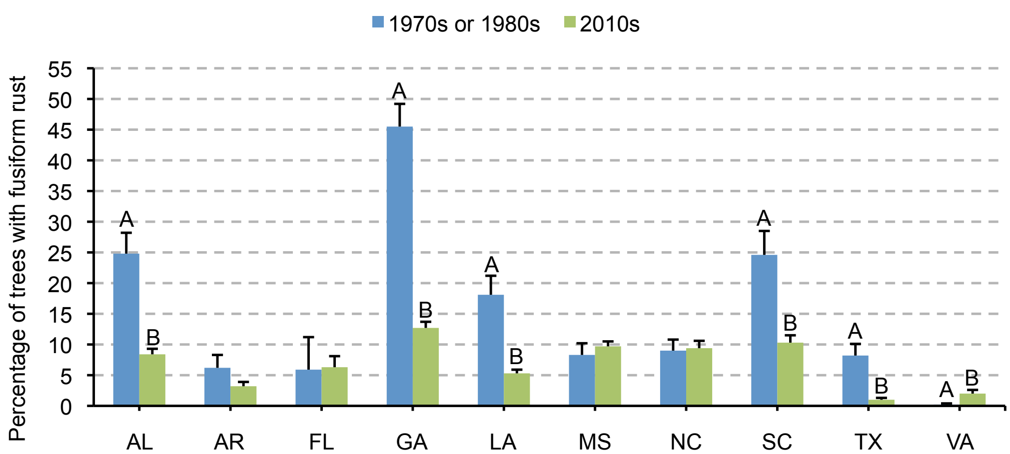

Figure 4—Estimated percentage of live trees (diameter at breast height ≥5 inches) with symptoms of fusiform rust in young (5 to 15 years old) loblolly pine plantations, by state and inventory decade. Bars extending from the columns represent one standard error. Within a state, columns with different letters are significantly different from one another (α=0.05).

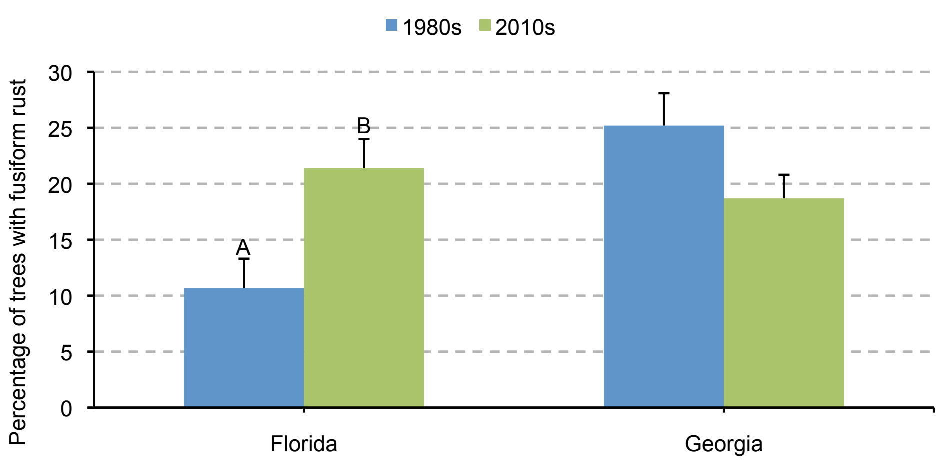

Figure 5—Estimated percentage of live trees (diameter at breast height ≥5 inches) with symptoms of fusiform rust in young (5 to 15 years old) slash pine plantations, by state and inventory decade. Bars extending from the columns represent one standard error. Within a state, columns with different letters are significantly different from one another (α=0.05).

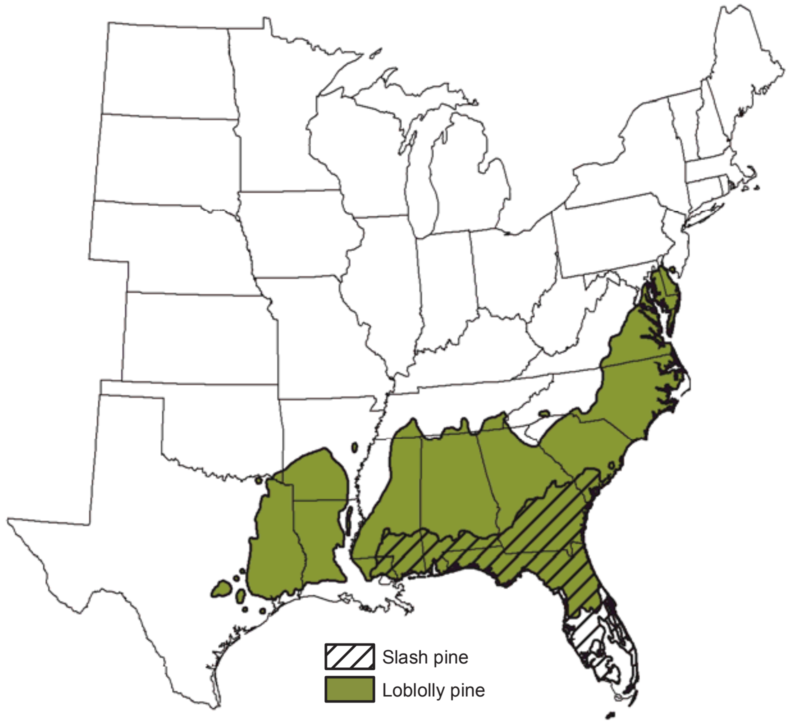

Figure 6—Historical ranges of slash pine (*Pinus elliottii*) and loblolly pine (*P. taeda*) in the eastern United States (U.S. Geological Survey 1999).

Anderson, R.L.; McClure, J.P.; Cost, N.; Uhler, R.J. 1986. Estimating fusiform rust losses in five southeast states. Southern Journal of Applied Forestry. 10(4): 237-240.

Aspinwall, M.J.; McKeand, S.E.; King, J.S. 2012. Carbon sequestration from 40 years of planting genetically improved loblolly pine across the southeast United States. Forest Science. 58(5): 446-456.

Bechtold, W.A.; Patterson, P.L., eds. 2005. The enhanced Forest Inventory and Analysis program – national sampling design and estimation procedures. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 85 p.

Brawner, J.T.; Carter, D.R.; Huber, D.A.; White, T.L. 1999. Projected gains in rotation-age volume and value from fusiform rust resistant slash and loblolly pines. Canadian Journal of Forest Research. 29: 737-742.

Cochran, W.G. 1977. Sampling techniques. 3rd ed. New York: John Wiley & Sons, Inc. 428 p.

Conner, R.C.; Hartsell, A.J. 2002. Chapter 16: Forest area and conditions. In: Wear, D.N.; Greis, J.G., eds. 2002. The southern forest resource assessment. Gen. Tech. Rep. SRS-53. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 357-402.

Cowling, E.; Randolph, K. 2013. Potentials for mutually beneficial collaboration between FIA specialists and IEG-40 pathologists and geneticists working on fusiform rust. Forests. 4: 1220-1231.

Cowling, E.; Young, C. 2013. Narrative history of the Resistance Screening Center: its origins, leadership and partial list of public benefits and scientific contributions. Forests. 4: 666-692.

ESRI®. 2010. ArcMAP™ 10.0. Redlands, California.

Fox, T.R.; Jokela, E.J.; Allen, H.L. 2007. The development of pine plantation silviculture in the southern United States. Journal of Forestry. 105(7): 337-347.

Li, B.; McKeand, S.; Weir, R. 1999. Tree improvement and sustainable forestry – impact of two cycles of loblolly pine breeding in the U.S.A. Forest Genetics. 6(4): 229-234.

McKeand, S.; Mullin, T.; Byram, T.; White, T. 2003. Deployment of genetically improved loblolly and slash pines in the South. Journal of Forestry. 101(3): 32-37.

Miles, P.D. 2015. Forest Inventory EVALIDator web-application, version 1.6.0.01. St. Paul, MN: U.S. Department of Agriculture Forest Service, Northern Research Station. http://apps.fs.fed.us/Evalidator/evalidator.jsp. [Date accessed: March 9, 2015].

O'Connell, B.M.; LaPoint, E.B.; Turner, J.A. [and others]. 2010. The Forest Inventory and Analysis database: Database description and users manual, version 5.1.4 for phase 2. Washington, DC: U.S. Department of Agriculture Forest Service. 537 p.

Phelps, W.R.; Czabator, F.L. 1978. Fusiform rust of southern pines. U.S. Department of Agriculture Forest Service Forest Insect and Disease Leaflet 26. http://www.na.fs.fed.us/spfo/pubs/fidls/fusiform/fidl-fusi.htm. [Date accessed: October 27, 2014].

Randolph, K.C.; Cowling, E.B.; Starkey, D.A. 2015. Long-term changes in fusiform rust incidence in the southeastern United States. Journal of Forestry. 113(4): 381-392.

Schmidt, R.A. 2003. Fusiform rust of southern pines: a major success for forest disease management. Phytopathology. 93: 1048-1051.

Squillace, A.E. 1976. Geographic patterns of fusiform rust infection in loblolly and slash pine plantations. Res. Note SE-232. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 4 p.

Starkey, D.A.; Anderson, R.L.; Young, C.H. [and others]. 1997. Monitoring incidence of fusiform rust in the south and change over time. Protection Rep. R8-PR 30. Atlanta, GA: U.S. Department of Agriculture Forest Service, Southern Region Forest Health Protection. 29 p.

USDA Forest Service. 2006. FIA glossary. http://socrates.lv-hrc.nevada.edu/fia/ab/issues/pending/glossary/Glossary_5_30_06.pdf. [Date accessed: September 29, 2014].

U.S. Geological Survey. 1999. Digital representation of “Atlas of United States Trees” by Elbert L. Little, Jr. http://gec.cr.usgs.gov/data/little. [Date accessed: November 25, 2013].

Vergara, R.; White, T.L.; Huber, D.A.; Schmidt, R.A. 2007. Realized genetic gains of rust resistant selections of slash pine (*Pinus elliottii* var. *elliottii*) planted in high rust hazard sites. Silvae Genetica. 56(5): 231-242.

Zarnoch, S.J.; Bechtold, W.A. 2000. Estimating mapped-plot forest attributes with ratios of means. Canadian Journal of Forest Research. 30: 688-697.

Zhao, D.; Kane, M. 2012. Differences in growth dynamics of loblolly and slash pine plantations in the southeastern United States. Forest Ecology and Management. 281: 84-92.