Status of *Sassafras albidum* (Nutt.) Nees in the Presence of Laurel Wilt Disease and Throughout the Eastern United States

KaDonna C. Randolph*

Abstract - *Sassafras albidum* (Sassafras) is an ecologically important tree species that is widely distributed throughout the eastern United States. Sassafras is presently threatened by *Raffaelea lauricola*, a fungus vectored by *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae; Redbay Ambrosia Beetle), which causes a lethal vascular wilt known as laurel wilt disease (LWD). This study summarizes the status of Sassafras across the entire eastern United States and in areas with LWD in particular, so that LWD-induced changes in the Sassafras resource may be properly understood. Inventory data collected by the Forest Inventory and Analysis (FIA) Program of the US Department of Agriculture Forest Service indicated that as of 2013–2014 there were 1.9 billion live Sassafras trees and saplings across 28 states, 53 ecoregion sections, and 69 forest types in the eastern United States. Only 1.7% of Sassafras trees ≥2.5 cm diameter at breast height occurred in counties with LWD; an additional 2.8% occurred in neighboring counties. To date, LWD has not reached the heart of the Sassafras range, yet discontinuous jumps of the disease beyond its advancing front suggest that future introductions may be possible. Landowners and forest managers within the range of Sassafras should be diligent to watch for LWD symptoms and consider the changes that may occur in their forests if the disease becomes established.

Introduction

Non-native phytophagous forest insects disrupt the economic, social, and ecosystem services and benefits provided by forest and urban trees, costing governments and homeowners millions and even billions of dollars annually (Aukema et al. 2011). Over 150 such insects have established themselves in the continental United States since 1930, and many have become major pests (Aukema et al. 2011, Moser et al. 2009). Included among the more recent and most detrimental introductions to the eastern United States is *Xyleborus glabratus* Eichhoff (Coleoptera: Curculionidae: Scolytinae; Redbay Ambrosia Beetle [RAB]), a native to Southeast Asia, which was first discovered at Port Wentworth near Savannah, GA in 2002 (Fraedrich et al. 2008).

The RAB carries spores of the fungus *Raffaelea lauricola* T.C. Harr., Fraedrich, & Aghayeva in its mandibular mycangia. The fungus is thought to be initially transmitted into healthy trees when the beetle excavates but then abandons the tunnels before laying eggs (Fraedrich et al. 2008). Once infected with *R. lauricola*, the trees become suitable for RAB brood production and typically die quickly, sometimes within a few weeks (Hughes et al. 2015). As observed on dead and dying *Persea*

*US Department of Agriculture, Forest Service, 4700 Old Kingston Pike, Knoxville, TN 37919; krandolph@fs.fed.us.

Manuscript Editor: Richard Baird

borbonia (L.) Spreng. (Redbay) trees, *R. lauricola* causes a lethal vascular wilt known as laurel wilt disease (LWD), so named because other members of the family Lauraceae, including *Sassafras albidum* (Nutt.) Nees (Sassafras), are also susceptible (Fraedrich et al. 2008, Hughes et al. 2015).

Following its introduction into the United States, LWD spread rapidly among Redbay trees along the southern Atlantic Coast (Fig. 1; Koch and Smith 2008). Early predictions suggested that the disease would not reach as far west as Texas until 2030 (Koch and Smith 2008); however, such predictions were unable to account for human-assisted spread and the ability of RAB to persist on Sassafras in the absence of Redbay. In addition to Georgia, LWD is now found in Alabama (Bates et al. 2013), Arkansas (Olatinwo et al. 2016), Florida (Smith et al. 2009), Louisiana (Fraedrich et al. 2015), Mississippi (Riggins et al. 2011), North Carolina (North Carolina Forest Service 2012), South Carolina (Fraedrich et al. 2008, Smith et al. 2009), and Texas (Menard et al. 2016). LWD progression beyond the coastal forest and on Sassafras, in particular, is concerning to individual landowners, municipalities, and others because of the cultural, ecological, and economic significance of lauraceous species (Hughes et al. 2015).

Like Redbay, Sassafras is an ecologically important tree species in the eastern United States. It is an early successional species that colonizes abandoned fields

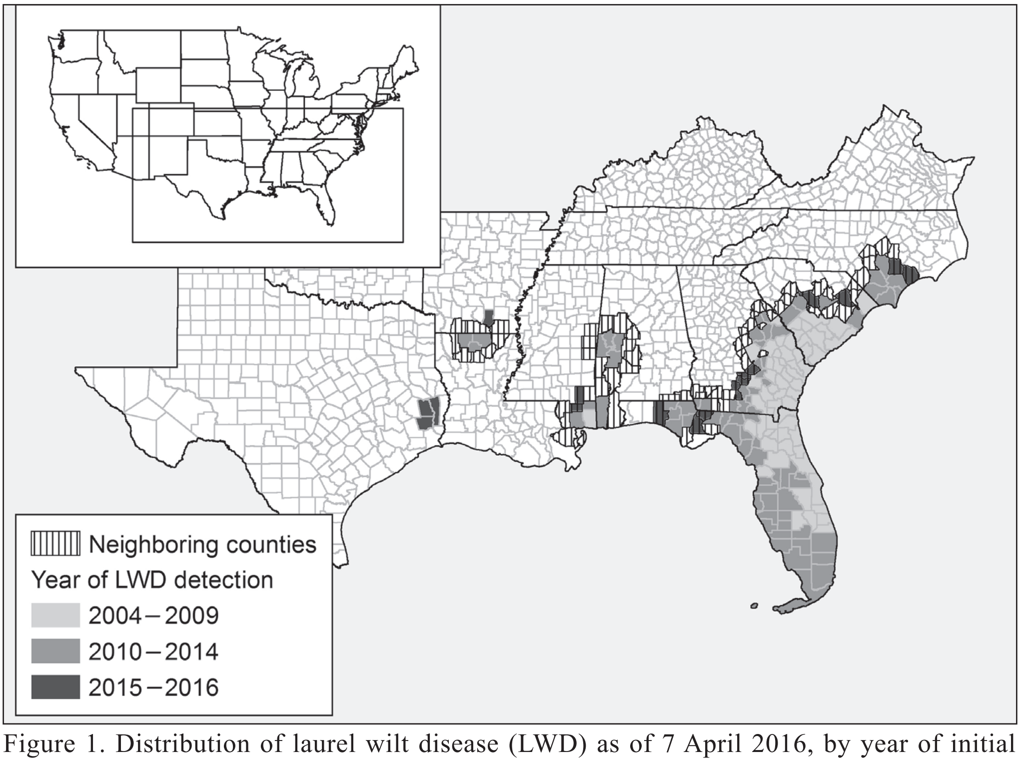

Figure 1. Distribution of laurel wilt disease (LWD) as of 7 April 2016, by year of initial detection (Southern Regional Extension Forestry 2016). Analyses of Sassafras in counties with LWD included only the counties where LWD was discovered prior to 2015 and where stated, their neighboring counties.

and often forms dense thickets through root suckering (Griggs 1990). Large Sassafras trees can also persist in later successional stands. Its bark, twigs, and leaves provide food for wildlife and insects (Griggs 1990). Two butterflies, *Papilio palamedes* Drury (Palamedes Swallowtail Butterfly) and *P. troilus* L. (Spicebush Swallowtail), preferentially utilize Laureaceae species, including Sassafras, for oviposition and larval feeding (Gramling 2010, Lederhouse et al. 1992). Sassafras wood is used for specialty wood products, and extracts from the leaves, bark, and roots are used for tea and perfume (Griggs 1990). With a range extending from the Great Lakes to the Gulf Coast and from the Atlantic Coast to Texas and Oklahoma (Fig. 2), the loss of Sassafras would affect much of the eastern forest ecosystem.

Most of the studies examining the effects of LWD have focused on Redbay at the local or subregional level, e.g., Cameron et al. (2015), Fraederich et al. (2008), and Shields et al. (2011). Exceptions to this include simulated responses to Sassafras mortality in central Kentucky forests (Nielsen and Rieske 2015), modeled spatiotemporal spread of LWD across the entire eastern United States using the ranges

Figure 2. Historical range of Sassafras (Little 1971) and the 37 states in the eastern United States that were included in the analysis (shaded in inset map). The area of central and west Texas was not included in the study.

of both Redbay and Sassafras (Koch and Smith 2008), and reported regional, i.e., population-level, responses of Redbay to LWD (Shearman et al. 2015). Both Koch and Smith (2008) and Shearman et al. (2015) found data from the Forest Inventory and Analysis (FIA) Program of the US Department of Agriculture Forest Service suitable for their regional studies but neither focused specifically on Sassafras. Thus, the objective of this study was to describe the status of Sassafras in the presence of LWD and across the eastern United States based on data collected by FIA so that future changes in the resource may be properly understood.

Methods

Data source

Field inventory. The FIA Program samples ground plots that are permanently located across the United States at a sampling intensity of 1 plot/~2400 ha (McRoberts 2005). Each plot is georeferenced and assigned to 1 of several spatially balanced "panels" whereby 1 panel of plots is measured every year so that each state is completely measured once every 5–10 years on an ongoing basis. Each plot consists of four 7.32-m fixed-radius subplots. Trees ≥12.7 cm in diameter at breast height (1.37 m above the ground; DBH) are measured on each subplot and trees <12.7 cm DBH are measured on a 2.07-m fixed-radius microplot located within each subplot. These data are available to the public through the FIA Program's online database (http://apps.fs.fed.us/fiadb-downloads/datamart.html [Accessed 26 February 2016]) (O'Connell et al. 2015). Of the multitude of variables collected by FIA, only a few were pertinent to this study: forest type, tree status, species, standing-dead status, and cause of death (USDA Forest Service 2014).

Forest type describes the species composition of the community in which trees are growing and is derived by FIA using a computer algorithm (Arner et al. 2003). Of particular interest for this study was the Sassafras/Eastern Persimmon forest type. For this forest type, Sassafras or *Diospyros virginiana* L. (Eastern Persimmon) forms the plurality of stocking for all live trees. Other species such as *Ulmus* spp. (elm), *Juniperus virginiana* L. (Eastern Redcedar), *Carya* spp. (hickory), *Fraxinus* spp. (ash), *Acer saccharum* Marsh. (Sugar Maple), *Liriodendron tulipifera* L. (Yellow-poplar), *Sophora affinis* Torr. & A. Gray (Texas Sophora), and *Quercus* spp. (oak) frequently occur in this forest type (USDA Forest Service 2014).

Tree status code describes whether a tree is alive, dead, or no longer present, i.e., has been cut and removed since the previous inventory (USDA Forest Service 2014). A dead tree qualifies as "standing-dead" if the bole has an unbroken actual length ≥1.37 m and leans less than 45° from vertical as measured from the base of the tree to 1.37 m up from the ground (USDA Forest Service 2014). Cause of death is estimated by the inventory crew for trees that die between plot visits, i.e., have a status change from live to dead. Possible causes of death include insect, disease, fire, animal, weather, suppression or competition from other vegetation, silvicultural or land clearing activity, and unknown or other.

Population estimates. Population estimates for various forest descriptors, e.g., forest land area and total number of live trees, are provided by the FIA Program through the online estimation tool EVALIDator (Miles 2016). Population estimates for any given year are calculated as a moving average, i.e., an equally weighted sum, of the most recently collected panel of data (~20% of all plots in each state) and the remaining panels collected in previous years (~80% of all plots in each state). Although measurements are spread over multiple years, the estimates typically are dated with the year of the most recently collected panel of data. For example, the estimate of total forest land area in Florida for the year 2014 is based on plots measured in 2010, 2011, 2012, 2013, and 2014. Because the data are collected over multiple years, it is best to view the estimates as representing the attribute of interest at some point between the first and last year of panel data collection (Patterson and Reams 2005).

Data analysis

Current status in the eastern United States. I obtained estimates from EVALIDator, by ecoregion section (Cleland et al. 2007) for 37 states in the eastern United States (Fig. 2), of (1) forest land area of the Sassafras/Eastern Persimmon forest type; (2) number of live Sassafras trees (DBH ≥ 12.7 cm), saplings (DBH ≥ 2.5 cm and DBH < 12.7 cm), and seedlings (DBH < 2.5 cm) on forest land; and (3) number of standing-dead Sassafras trees (DBH ≥ 12.7 cm) on forest land. The most recent year of data collection included in these estimates was 2013 for Kentucky, Louisiana, Tennessee, and Virginia, and 2014 for all other states. Data from central and west Texas (Fig. 2) were not included.

The distribution of the number of live Sassafras stems (DBH ≥ 2.5 cm)/ha across the eastern United States was generated by Koch and Smith (2008). Instead of repeating their analysis, I divided the distributions of the number of Sassafras trees (live and dead), saplings, and seedlings/ha of forest land across the ecoregion sections by quartiles and classified each ecoregion section according to whether the number of stems/ha, i.e., Sassafras density, in the ecoregion section was in the first, second, third, or fourth quartile. In addition, I calculated Sassafras percent standing-dead for each ecoregion section as the ratio of the number of standing-dead trees in the ecoregion section to the total number of live trees plus standing-dead trees in the ecoregion section expressed as a percentage.

I obtained estimates of the number of live and standing-dead Sassafras trees in counties with LWD and in their neighboring counties (Fig. 1) from EVALIDator. I calculated Sassafras percent standing-dead for each group of counties as the ratio of the number of standing-dead trees in the group of counties to the total number of trees (live plus standing-dead) in the group of counties expressed as a percentage. To match the timeframe of the data available in the FIA database at the time of this analysis, only counties where LWD discoveries were made prior to 2015 (Hoyle 2016) were used to delineate the 2 sets of counties.

Recent mortality in counties with laurel wilt disease. I assigned all trees and saplings measured by FIA in counties with LWD (Fig. 1) a "year of LWD" according to the year of LWD detection (Hoyle 2016). For trees and saplings measured more than once, I included in the analysis only the most recent assessment prior to

LWD confirmation ("before LWD") and only the most recent assessment following LWD confirmation ("after LWD"), i.e., only 2 assessments/tree or sapling. Trees and saplings measured in the same year as LWD discovery were retained for the "after" assessment regardless of when, i.e., what month, they were assessed.

Assignments of trees and saplings to 1 of 2 categories (either "survivors" or "mortality") were made on the basis of tree status code. I labeled trees or saplings with a status code of live at both assessments as survivors and trees or saplings with a status code of live before LWD and dead after LWD as mortality. I assigned to the survivor class trees or saplings that were alive after LWD but had no status before LWD (missed or ingrowth stems). Trees or saplings with a status code of live before LWD and removed after LWD were not included in the analysis because it was not known if they were alive or dead at the time of removal. I also excluded trees and saplings that were alive before LWD but had no status after LWD.

I built a 2 x 2 contingency table with the before and after dataset and used a Rao-Scott chi square test of independence to test for an association between species group, i.e., Sassafras or non-Sassafras ("other species"), and survivorship. So that the proportion of mortality for the non-Sassafras group would not be inflated, I excluded *Persea* species from the analysis. The test was performed using the SAS procedure SURVEYFREQ (SAS Institute, Inc. 2010) which takes into account the FIA sampling design whereby a correlation exists among trees growing on the same plot. In addition to the test of independence, I summarized causes of death for the mortality trees by species group.

Results

Current status in the eastern United States

Area of the Sassafras/Eastern Persimmon forest type. Across the eastern United States, Sassafras was observed in 69 different forest types from both the softwood and hardwood forest type groups (Appendix 1; USDA Forest Service 2014). The Sassafras/Eastern Persimmon forest type covered an estimated 898,000 ha of forest land across 53 ecoregion sections (Fig. 3). The Sassafras/Eastern Persimmon forest type constituted as much as 5.1% of the total forest land area within a single ecoregion section, but overall the forest type covered <1% of the total forest land area in all 53 ecoregion sections (Table 1). Because the Sassafras/Eastern Persimmon forest type may be dominated by either Sassafras or Eastern Persimmon, forest land designated as this forest type may include only Sassafras or only Eastern Persimmon. Such was the case with the following ecoregion sections for which the Sassafras/Eastern Persimmon forest type included only Eastern Persimmon: 232G in Florida, 232L along the Gulf of Mexico, and 234E, 251E, 251F, 255A, 255D, 332F, and M231A throughout Arkansas, Kansas, Missouri, Oklahoma, and Texas (Fig. 3). Without these 9 ecoregion sections, the total forest land area of the Sassafras/Eastern Persimmon forest type was estimated to be 769,000 ha (Table 1).

Status across all forest types. Sassafras was most abundant in ecoregion section 223A where there were an estimated 273.3 million live trees and saplings and 2.39 billion seedlings (Table 2). There were also an estimated 4.4 million dead Sassafras

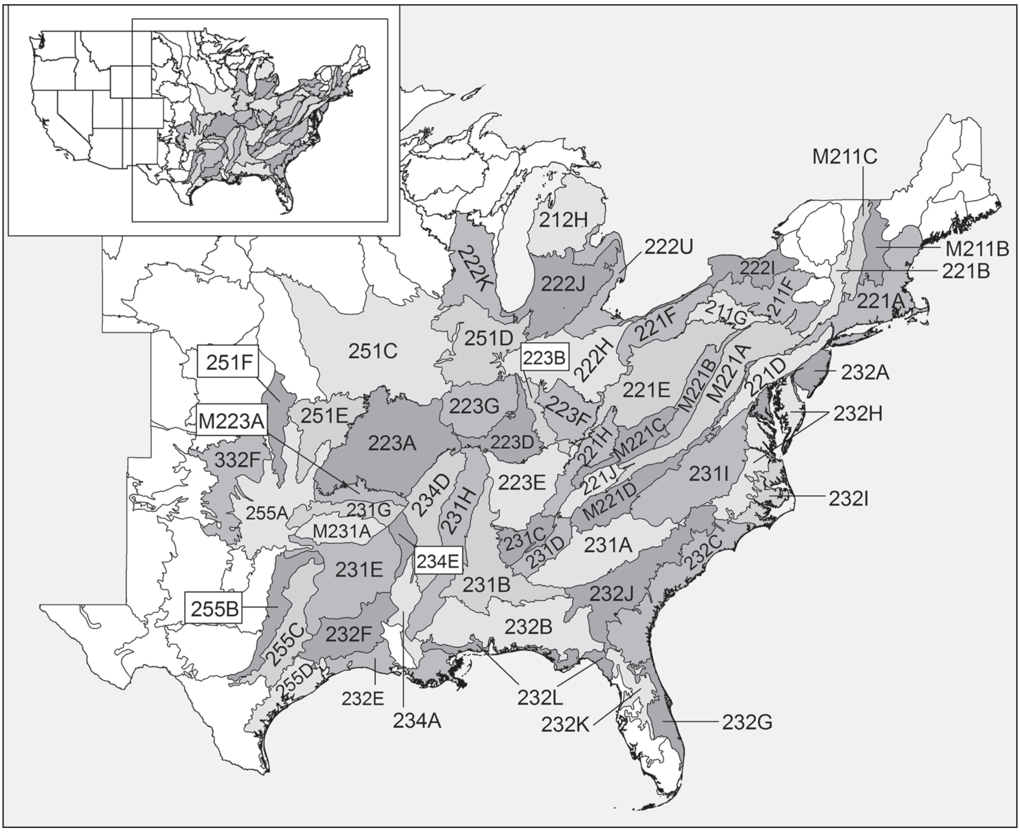

Figure 3. Ecoregion sections where Sassafras trees, saplings, seedlings, or the Sassafras/Eastern Persimmon forest type were found (shaded).

Table 1. Area of the Sassafras/Eastern Persimmon forest type in the eastern United States, by ecoregion section. SE = sampling error as a percent of the estimate. A 68.27% confidence interval for the estimate can be calculated as estimate ± estimate * (SE/100). Source: Miles (2016).

	Sassafras/Eastern Persimmon forest type		All forest types	
Ecoregion section[A]	Estimate (thousand ha)	SE (%)	Estimate (thousand ha)	SE (%)
211F	5.7	71.3	2489.7	2.4
211G	2.7	101.8	1624.5	2.7
221A	3.6	79.1	3130.2	1.8
221B	2.4	99.0	669.7	5.3
221D	4.5	58.4	864.2	4.2
221E	78.7	17.1	5245.5	1.3
221F	9.5	45.1	1143.1	3.6
221H	8.7	50.2	2415.6	2.1
221J	11.2	41.3	814.8	4.1
222H	4.6	49.1	897.8	3.6
222J	17.9	34.3	1459.2	2.5
222U	6.5	57.6	362.8	7.4
223A	43.5	20.4	6349.3	1.0

trees in this ecoregion section; only ecoregion sections 221E (13.6 million trees), 223E (5.7 million trees), M221C (5.6 million trees), and 223D (5.3 million trees) had more dead Sassafras trees (Table 2). In ecoregion sections 232C and 232J, which encompass many of the counties in Georgia, North Carolina, and South

Table 1, continued.

	Sassafras/Eastern Persimmon forest type		All forest types	
Ecoregion section[A]	Estimate (thousand ha)	SE (%)	Estimate (thousand ha)	SE (%)
223B	10.4	39.5	633.3	4.4
223D	28.2	22.4	1492.9	2.5
223E	50.4	19.4	2717.3	1.9
223F	14.7	34.5	1050.5	2.9
223G	16.8	30.0	815.4	3.7
231A[B]	13.3	36.2	5143.8	1.5
231B	23.5	28.8	5577.9	1.5
231C[B]	9.0	47.9	1422.5	3.2
231D	4.3	61.3	1305.4	3.4
231E	38.4	22.7	6183.3	1.2
231G	28.3	27.2	1204.4	4.0
231H	25.1	26.4	3697.1	1.7
231I	16.3	32.6	4982.3	1.3
232A	4.6	66.3	735.1	4.2
232B	82.6	15.7	8113.7	1.1
232C[B]	7.8	46.3	5523.2	1.5
232F	1.2	70.7	4034.8	1.5
232G[C]	5.1	60.5	1014.1	4.4
232H	7.3	47.5	2308.7	2.2
232I	2.8	74.6	1392.2	3.0
232J	59.9	18.4	5334.5	1.7
232K[B]	5.4	60.4	1028.1	4.1
232L[C]	7.3	58.0	1915.3	3.0
234A	12.7	40.5	1069.3	3.9
234D	13.4	36.3	1095.4	3.6
234E[C]	4.7	57.2	462.9	6.2
251C	6.2	57.8	2385.3	2.2
251D	2.6	65.8	314.5	7.1
251E[C]	2.6	84.0	656.2	5.2
251F[C]	3.4	98.7	181.5	11.8
255A[C]	84.2	20.0	2161.0	2.8
255C[B]	8.9	44.9	654.5	5.5
255D[C]	4.8	71.4	94.6	15.0
332F[C]	5.0	93.4	483.5	7.7
M221A	22.2	33.0	4030.5	1.7
M221B	13.9	41.2	2048.8	2.7
M221C	10.8	46.3	2511.5	2.3
M221D	16.0	35.3	3452.1	1.8
M223A[B]	12.8	40.9	1234.7	3.3
M231A[C]	11.7	43.3	2336.3	2.0

[A]Geographic locations are shown in Figure 3. Descriptive names are listed in Appendix 2.
[B]Only Sassafras seedlings (DBH < 2.5 cm) were observed.
[C]Presence of the Sassafras/Eastern Persimmon forest type due to Eastern Persimmon.

Table 2. Number of live sassafras trees (DBH ≥ 12.7 cm), live saplings (DBH ≥ 2.5 and DBH < 12.7 cm), live seedlings (DBH < 2.5 cm), and standing-dead Sassafras trees (DBH ≥ 12.7 cm) in the eastern United States, by ecoregion section. SE = sampling error as a percent of the estimate. A 68.27% confidence interval for the estimate can be calculated as estimate ± estimate * (SE/100). Source: Miles (2016).

	Live trees		Live saplings		Live seedlings		Standing-dead trees	
Ecoregion section[A]	Estimate (thousands)	SE (%)	Estimate (thousands)	SE (%)	Estimate (millions)	SE (%)	Estimate (thousands)	SE (%)
211F	4906	28.8	2272	58.6	54.8	46.1	146	54.0
211G	3409	34.8	6874	34.3	103.8	29.7	563	40.8
212H	1353	47.2	8862	34.1	110.9	19.6	168	47.8
221A	4090	17.7	21,362	22.3	153.3	19.7	892	29.8
221B	1349	51.0	564	94.3	5.7	50.9	236	59.7
221D	4215	17.2	11,896	26.4	61.4	22.3	1212	24.9
221E	38,073	8.3	168,332	9.8	1294.5	8.6	13,597	10.2
221F	3720	23.8	12,362	29.6	64.3	27.0	422	35.5
221H	8818	13.1	80,349	12.9	1188.6	7.6	3828	18.7
221J	6670	17.3	24,755	24.7	357.2	17.4	2002	35.3
222H	3891	24.9	7592	30.9	67.4	21.6	1145	27.4
222I	287	51.1	-	-	8.3	61.3	39	100.0
222J	13,933	14.8	36,918	18.1	489.3	15.8	2404	20.2
222K	24	97.8	-	-	0.3	97.8	-	-
222U	1826	34.2	7224	40.9	34.1	37.6	37	104.0
223A	16,365	7.9	256,960	6.3	2394.7	4.1	4398	13.4
223B	7450	12.7	34,654	15.6	356.1	17.4	2354	17.0
223D	13,950	9.5	70,142	13.6	614.4	8.6	5267	11.1
223E	17,357	10.7	50,380	17.2	668.1	10.2	5698	13.8
223F	6567	14.5	22,636	19.2	127.8	15.5	1968	21.1
223G	11,954	12.6	43,609	16.8	217.8	12.7	1629	20.5
231A	642	23.6	27,818	19.8	115.2	14.6	138	50.0
231B	2501	15.7	62,672	12.1	338.2	9.1	598	26.1
231C	1687	25.8	17,591	18.8	205.9	18.2	577	32.9
231D	582	31.8	14,388	25.8	165.4	15.7	194	49.8
231E	3495	16.3	78,052	14.6	319.5	9.3	812	26.9
231G	684	42.4	5082	58.6	43.3	39.0	114	56.7
231H	6783	14.1	35,429	18.8	173.6	11.3	2057	20.6
231I	2021	31.6	18,869	19.7	209.5	12.2	493	32.0
232A	5511	18.1	21,518	25.5	37.1	41.1	946	27.2
232B	1911	16.2	37,757	14.7	491.9	12.1	249	38.0
232C	253	47.5	16,073	24.2	128.8	23.9	34	102.5
232E	39	97.2	446	101.0	2.3	52.8	-	-
232F	1728	17.5	37,594	17.3	289.5	14.1	180	44.7
232H	2114	20.2	29,852	18.9	139.7	17.2	438	34.1
232I	599	87.3	5680	42.1	18.4	29.4	-	-
232J	388	30.5	26,664	17.5	513.6	9.1	243	66.5
232K	-	-	-	-	5.0	54.4	-	-
232L	71	71.7	-	-	3.3	73.6	71	71.7
234A	179	53.4	460	100.2	5.3	48.1	-	-
234D	1609	26.4	13,943	51.0	21.6	26.2	234	39.5
234E	-	-	4053	43.1	5.0	43.4	36	100.2
251C	3366	22.8	24,470	23.2	126.4	19.0	179	45.6
251D	2063	31.1	14,696	23.7	179.7	21.3	212	49.6

Carolina with LWD, percent standing-dead was 11.8% and 38.5%, respectively. No live Sassafras trees or saplings were observed in 4 ecoregion sections and no standing-dead Sassafras trees were recorded in 9 ecoregion sections (Table 2). Only standing-dead Sassafras trees, i.e., no live Sassafras trees, saplings, or seedlings, were recorded in section 251E.

Overall, the greatest abundance of Sassafras was located in the interior eastern United States. Nine ecoregion sections were in the top, i.e., fourth quartile, in terms of live Sassafras seedling, sapling, and tree density (Fig. 4). These ecoregion sections were located in 2 general geographical areas. First, ecoregion sections 222J, 223B, 223D, 223G, and 251D form a crescent shape from southern Michigan, through Illinois, and into southern Indiana and western Kentucky (Fig. 4). Secondly, ecoregion sections 221E, 221J, M221A, and M221C form a y-shape from Tennessee in the south to 2 endpoints in Pennsylvania, one through Ohio and West Virginia and the other through Virginia and Maryland (Fig. 4). Ecoregion sections in the top quartile in terms of standing-dead Sassafras trees/ha of forest land were concentrated in ecoregion sections spanning Indiana, Kentucky, Ohio, Tennessee, and West Virginia (Fig. 4).

As expected, fewer Sassafras stems were found at the edges of its historic range (Fig. 2). Ecoregion sections in the bottom, i.e., first quartile, in terms of live Sassafras seedling, sapling, and tree density were located in northern Illinois, New Hampshire, eastern Oklahoma, and along the coast of the Gulf of Mexico (Fig. 4). Ecoregion sections in the bottom quartile in terms of dead Sassafras trees/ha of forest land were similarly located (Fig. 4).

Sassafras was abundant as seedlings and saplings in some ecoregion sections without being highly abundant as trees. In 8 ecoregion sections, the density of seedlings and saplings was in the upper 2 quartiles, whereas the density of trees was

Table 2, continued.

	Live trees		Live saplings		Live seedlings		Standing-dead trees	
Ecoregion section[A]	Estimate (thousands)	SE (%)	Estimate (thousands)	SE (%)	Estimate (millions)	SE (%)	Estimate (thousands)	SE (%)
251E	-	-	-	-	-	-	36	101.8
255A	36	100.7	5020	98.7	15.3	61.2	36	100.7
255B	-	-	-	-	0.5	98.8	-	-
255C	848	30.6	3271	46.7	33.5	31.0	295	42.6
255D	-	-	485	97.0	-	-	-	-
M211B	76	104.4	-	-	0.6	96.0	-	-
M211C	-	-	-	-	6.6	101.5	-	-
M221A	21,224	9.7	83,572	11.4	922.4	10.1	4363	12.5
M221B	8556	16.2	45,491	18.6	486.4	16.9	2965	17.2
M221C	11,565	10.1	98,056	13.5	945.0	10.2	5636	12.3
M221D	8195	12.9	58,784	14.8	821.3	8.5	3980	14.1
M223A	1708	23.0	15,006	24.0	193.0	16.7	433	33.5
M231A	470	64.8	8675	30.0	29.2	24.3	142	101.6

[A]Geographic locations are shown in Figure 3. Descriptive names are listed in Appendix 2.

in the lower 2 quartiles (Fig. 4). Many of these ecoregion sections were located in areas dominated by *Pinus taeda* L. (Loblolly Pine) and *P. echinata* Mill. (Shortleaf Pine) forest types (USDA Forest Service and USDI Geological Survey 2000), e.g., eastern Texas, western Louisiana, and a crescent along the coastal plain from Mississippi to Virginia.

Status in counties with laurel wilt disease. Only 1.7% of the total live inventory of Sassafras trees and saplings was in counties where LWD was discovered prior to 2015; another 2.8% was in their neighboring counties. The estimated number of live Sassafras trees was 873,800 trees in the counties with LWD and 2 million trees in the neighboring counties. Percent standing-dead was higher in the counties with LWD (24.7%) than in the neighboring counties (20.2%).

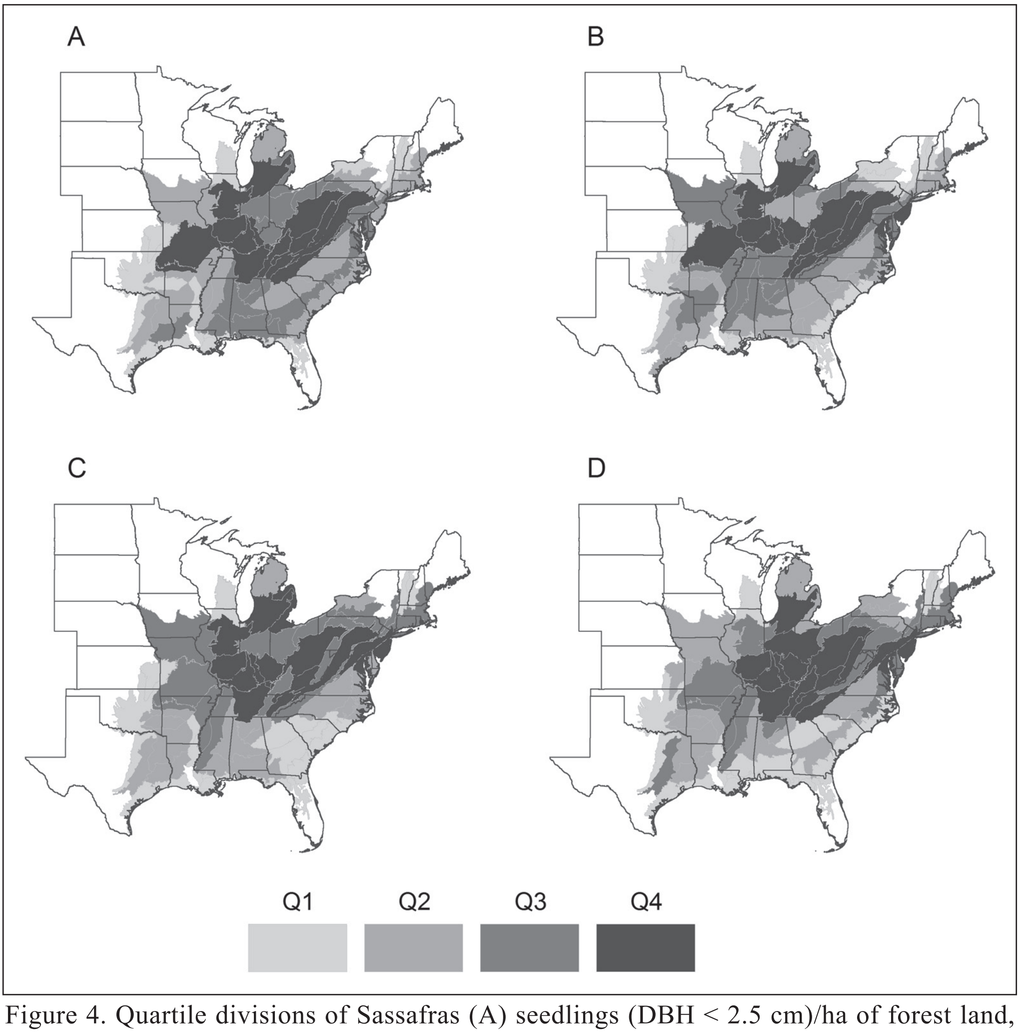

Figure 4. Quartile divisions of Sassafras (A) seedlings (DBH < 2.5 cm)/ha of forest land, (B) saplings (DBH ≥ 2.5 cm and DBH < 12.7 cm)/ha of forest land, (C) live trees (DBH ≥ 12.7 cm)/ha of forest land, and (D) standing-dead trees (DBH ≥ 12.7 cm)/ha of forest land by ecoregion section. Q1 = first quartile, Q2 = second quartile, Q3 = third quartile, Q4 = fourth quartile.

Recent mortality in counties with laurel wilt disease

In the counties where LWD was discovered between 2002 and 2014, 62 plots containing Sassafras trees or saplings were assessed before and after the discovery of LWD. One plot was omitted from the analysis due to an excessively long time period between plot visits (19 years). The remaining 61 plots were measured, on average, 4.6 years before LWD discovery (range = 1–10 years) and 1.6 years after LWD discovery (range = 0–5 years). The mean time between measurements was 6.2 years (range = 3–11 years).

Results of the Rao-Scott chi-square test of independence indicated that there was a significant ($F = 43.5$, $P < 0.0001$) relationship between species group and survivorship across the plots in the LWD counties. Of the Sassafras trees and saplings ($n = 93$), 36.6% died during the remeasurement period, compared to only 8.8% mortality among other species ($n = 1783$). Silvicultural/land-clearing activity and competition or suppression from other vegetation were the most frequently recorded causes of death for both Sassafras and other species (Fig. 5).

Discussion

With <5% of its total live inventory in counties with LWD and their neighboring counties, only a small portion of Sassafras is immediately threatened by the disease. However, discoveries of LWD on Sassafras in Alabama, Arkansas, and Louisiana (Bates et al. 2013, Fraedrich et al. 2015, Olatinwo 2016), where it was first thought that RAB would not be a threat due primarily to the absence of Redbay, suggest that the abundance of Sassafras located in the interior eastern United States is also at

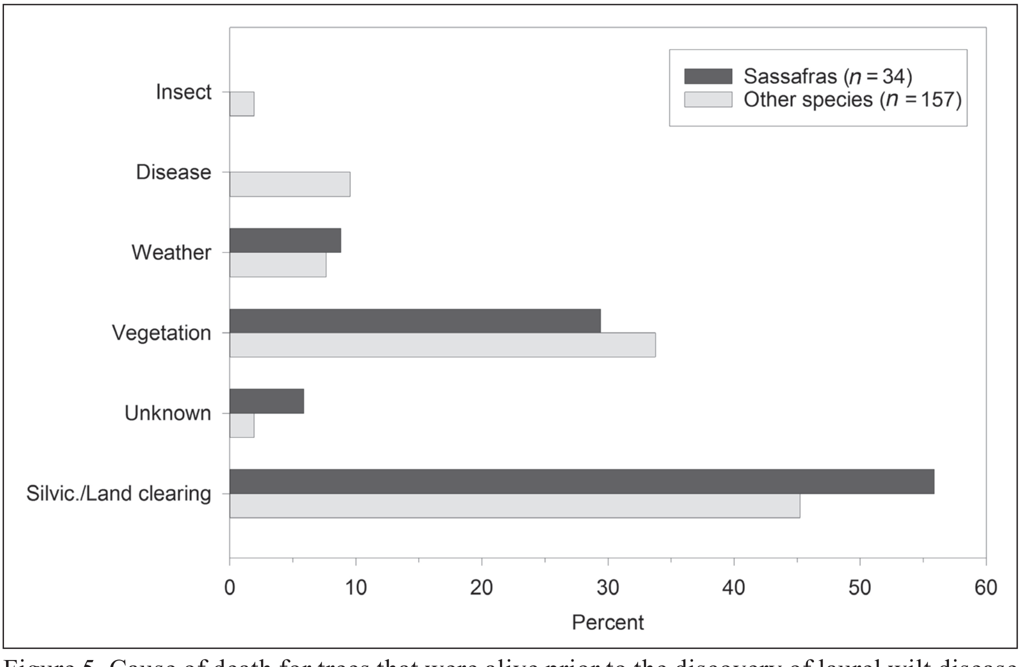

Figure 5. Cause of death for trees that were alive prior to the discovery of laurel wilt disease (LWD) and dead after LWD was discovered. Silvic. = Silviculture. n = number of trees.

risk. Climate-matching techniques employed by Koch and Smith (2008) predicted that RAB would be constrained to the southeastern coastal plain and perhaps a small area in the southern Appalachian Mountains. Yet recent cold-tolerance tests have indicated that RAB can survive temperatures as low as -24 °C (Formby et al. 2013); therefore, it is possible that RAB could survive farther north than previously anticipated. If this is indeed the case, the spread of LWD into the interior eastern United States could devastate Sassafras and alter many different forest types.

Though mortality of Sassafras trees following establishment of LWD was greater than that observed for other tree species, results suggested that LWD was not the primary cause. Instead, estimated causes of death pointed to silvicultural/land-clearing activities and competition or suppression from other vegetation. There are at least 2 possible explanations for the lack of Sassafras mortality attributed to LWD. First, LWD-mortality may have been incorrectly attributed to another factor or recorded as "unknown" by the inventory crews due to the relative novelty of the disease and complexity of identifying the causality of tree mortality (Franklin et al. 1987). Without a detailed inspection for LWD symptoms, e.g., sapwood discoloration or beetle frass tubes, LWD-induced mortality resembles typical Sassafras mortality and provides little reason to suspect LWD without a priori knowledge of its presence. Second, the after-LWD assessments may have been made too soon after the discovery of LWD. Sixty-one percent of the assessments were made within ~1 year after LWD was detected in the county. Whether LWD infections were localized or ubiquitous in the county was unknown. Thus, the plots with Sassafras could have been located in areas to which LWD had not yet spread or in stands where LWD was progressing slowly. In a study in southeastern Georgia, Cameron et al. (2015) observed 40% mortality among Sassafras 1 year after symptoms of LWD first appeared and >80% mortality 1.5 years later, i.e., 2.5 years after the first symptoms. Thus, subsequent assessments may show an increase in Sassafras mortality directly and more obviously attributable to LWD.

Unlike in most stands of Redbay, studies have shown that the spread of LWD in Sassafras stands is inconsistent, moving rapidly and completely through some stands while abating before complete devastation in others (Cameron et al. 2015). This inconsistency, perhaps, favors the perpetuation of the species. Nevertheless, given that Sassafras trees generally succumb to competitive stress if they are unable to reach the upper (unshaded) canopy (Griggs 1990), the presence of the RAB, which preferentially attacks larger trees first (Cameron et al. 2015, Mayfield and Brownie 2013), adds pressure to the survivability of individual Sassafras trees.

Continued region-wide monitoring of Sassafras by the FIA Program and the implementation of other localized studies will be important for assessing the loss of Sassafras as LWD progresses throughout the eastern United States. For example, Brandeis et al. (2016) already has noted that almost 41% of the Sassafras trees (DBH $\geq$ 2.5 cm) measured during the 2009 FIA survey of the state of Georgia had died by the time the 2014 survey was completed. In order to better understand future potential impacts, spatio-temporal models that take into account the ability of RAB to thrive in the absence of Redbay and that incorporate human-assisted spread ahead of the advancing front of LWD should be developed. This need is especially important since eradication of LWD in the United States is no longer considered feasible (Hughes et al. 2015).

Minimizing the effects of LWD in established areas and slowing its spread to new sites are the current recommended management actions (Hughes et al. 2015). Because *R. lauricola* has been observed to spread through the interconnected clonal root systems of Sassafras (Cameron et al. 2014), one possible way to minimize its spread would be to sever the root systems with heavy mechanical equipment (Hughes et al. 2015), although this hardly seems feasible in a forested setting. Likewise, the use of fungicides and insecticides in a forested setting would be cost-prohibitive due to the need for repeated applications (Hughes et al. 2015). Public awareness campaigns, such as dontmovefirewood.org, active monitoring of trees on the leading edge of the disease, and the removal of dead trees through sanitation cuts are among the management techniques most likely to help slow the spread of LWD throughout the broad range of ecological gradients and forest types in which Sassafras occurs in the eastern United States.

LWD-induced Sassafras mortality will alter the forest both structurally and compositionally, and will also affect ecological interactions. With the exception of clonal thickets, Sassafras does not typically dominate a forest stand but is instead a minor to moderate component of a variety of forest types across the eastern United States (Griggs 1990). As such, the direct effects of Sassafras decline may be modest; however, the indirect effects, especially in terms of resources released for use by other species, will be measurable and likely complex (Nielsen and Rieske 2015). In a simulation study of the effects of LWD-induced Sassafras mortality in forests of central Kentucky, Nielsen and Rieske (2015) found that losses in Sassafras basal area can be offset by the increased growth of other species, particularly Yellow-poplar and *Acer rubrum* L. (Red Maple). The timing and extent of the response by other species will depend on the degree to which Sassafras disappears from the stand, as well as the size and species composition of the remaining forest. Dynamics within canopy gaps resulting from tree mortality are complex (Beckage et al. 2008, Oliver and Larson 1996); therefore, the effect of losing Sassafras in one forest type or stand may be very different than in another.

Since the RAB was introduced in 2002, LWD has been moving gradually across the coastal plain (Fig. 1) where Sassafras is minimally abundant (Fig. 4). If and when LWD establishes itself in the more-centrally located forests where Sassafras is most abundant (Fig. 4), the impact of LWD on Sassafras will increase and studies similar to Shearman et al. (2015) can be completed. Landowners and forest managers in the heart of Sassafras' range should be diligent to watch for LWD symptoms because discontinuous jumps of the disease may continue. Forest managers are encouraged to survey stands that include Sassafras and consider the changes that may occur if LWD becomes established and how such changes will affect their management objectives.

Acknowledgments

Gratitude is extended to Sue Crocker, Anita Rose, and 2 anonymous reviewers for their comments on earlier drafts of this manuscript, and to the numerous forest inventory field crews who collected the data used in this study.

Literature Cited

Arner, S.L, S. Woudenberg, S. Waters, J. Vissage, C. MacLean, M. Thompson, and M. Hansen. 2003. National algorithms for determining stocking class, stand size class, and forest type for Forest Inventory and Analysis plots. US Department of Agriculture Forest Service, Forest Inventory and Analysis Program. 65 pp. Available online at http://www.fia.fs.fed.us/library/sampling/docs/supplement4_121704.pdf. Accessed 23 May 2016.

Aukema, J.E., B. Leung, K. Kovacs, C. Chivers, K.O. Britton, J. Englin, S.J. Frankel, R.G. Haight, T.P. Holmes, A.M. Liebhold, D.G. McCollough, and B. Von Holle. 2011. Economic impacts of non-native forest insects in the continental United States. PLoS ONE 6(9):e24587.

Bates, C.A., S.W. Fraedrich, T.C. Harrington, R.S. Cameron, R.D. Menard, and G.S. Best. 2013. First report of laurel wilt, caused by *Raffaelea lauricola*, on Sassafras (*Sassafras albidum*) in Alabama. Plant Disease 97(5):688.

Beckage, B., B.D. Kloeppel, J.A. Yeakley, S.F. Taylor, and D.C. Coleman. 2008. Differential effects of understory and overstory gaps on tree regeneration. The Journal of the Torrey Botanical Society 135(1):1–11.

Brandeis, T.J., J.M. McCollum, A.J. Hartsell, C. Brandeis, A.K. Rose, S.N. Oswalt, J.T. Vogt, and H.M. Vega. 2016. Georgia's forests, 2014. Resour. Bull. SRS-209. US Department of Agriculture Forest Service, Southern Research Station, Asheville, NC. 78 pp.

Cameron, R.S., C. Bates, and J. Johnson. 2014. Progression of laurel wilt disease in Georgia: 2009–2011 (Project SC-EM-08-02). Pp. 145–151, *In* K.M. Potter and B.L. Conkling (Eds.). Forest health monitoring: National status, trends, and analysis 2012. General Technical Report SRS-198. US Department of Agriculture Forest Service, Southern Research Station, Asheville, NC. 192 pp.

Cameron, R.S., J. Hanula, S. Fraedrich, and C. Bates. 2015. Progression and impact of laurel wilt disease within Redbay and Sassafras populations in southeast Georgia. Southeastern Naturalist 14(4):650–674.

Cleland, D.T., J.A. Freeouf, J.E. Keys, Jr., G.J. Nowacki, C. Carpenter, and W.H. McNab. 2007. Ecological subregions: Sections and subsections of the conterminous United States [1:3,500,000] [CD-ROM]. A.M. Sloan (Cartog.). General Technical Report WO-76. US Department of Agriculture Forest Service, Washington, DC.

Formby, J.P., N. Krishnan, and J.J. Riggins. 2013. Supercooling in the Redbay Ambrosia Beetle (Coleoptera: Curculionidae). Florida Entomologist 96(4):1530–1540.

Fraedrich, S.W., T.C. Harrington, R.J. Rabaglia, M.D. Ulyshen, A.E. Mayfield III, J.L. Hanula, J.M. Eickwort, and D.R. Miller. 2008. A fungal symbiont of the Redbay Ambrosia Beetle causes a lethal wilt in Redbay and other Lauraceae in the southeastern United States. Plant Disease 92:215–224.

Fraedrich, S.W., C.W. Johnson, R.D. Menard, T.C. Harrington, R. Olatinwo, and G.S. Best. 2015. First report of *Xyleborus glabratus* (Coleoptera: Curculionidae: Scolytinae) and laurel wilt in Louisiana, USA: The disease continues westward on Sassafras. Florida Entomologist 98(4):1266–1268.

Franklin, J.F., H.H. Shugart, and M.E. Harmon. 1987. Tree death as an ecological process: The causes, consequences, and variability of tree mortality. BioScience 37(8):550–556.

Gramling, J.M. 2010. Potential effects of laurel wilt on the flora of North America. Southeastern Naturalist 9(4):827–836.

Griggs, M.M. 1990. *Sassafras albidum* (Nutt.) Nees. *In* R.M. Burns and B.H. Honkala (Tech. Coords.). Silvics of North America: Vol 2. Hardwoods. Agriculture Handbook 654. US Department of Agriculture Forest Service, Washington, DC. 877 pp.

Hoyle, Z. 2016. Laurel wilt continues to spread. CompassLive 9 February 2016. US Department of Agriculture Forest Service, Southern Research Station. Available online at http://www.srs.fs.usda.gov/compass/2016/02/09/laurel-wilt-continues-to-spread/. Accessed 12 February 2016.

Hughes, M.A., J.A. Smith, R.C. Ploetz, P.E. Kendra, A.E. Mayfield III, J.L. Hanula, J. Huler, L.L. Stelinski, S. Cameron, J.J. Riggins, D. Carrillo, R. Rabaglia, J. Eickwort, and T. Pernas. 2015. Recovery plan for laurel wilt on Redbay and other forest species caused by *Raffaelea lauricola* and disseminated by *Xyleborus glabratus*. Plant Health Progress 16(4):173–210.

Koch, F.H., and W.D. Smith. 2008. Spatio-temporal analysis of *Xyleborus glabratus* (Coleoptera: Circulionidae: Scolytinae) invasion in eastern US forests. Environmental Entomology 37(2): 442–452.

Lederhouse, R.C., M.P. Ayres, J.K. Nitao, and J.M. Scriber. 1992. Differential use of lauraceous hosts by swallowtail butterflies, *Papilio troilus* and *P. palamedes* (Papilionidae). Oikos 63(2):244–252.

Little, Jr., E.L. 1971. Atlas of United States trees. Volume 1. Conifers and important hardwoods. Miscellaneous Publication 1146. US Department of Agriculture. 9 pp. 200 maps. Available online at http://esp.cr.usgs.gov/data/little. Accessed 22 February 2016.

Mayfield, A.E., III, and C. Brownie. 2013. The Redbay Ambrosia Beetle (Coleoptera: Curculionidae: Scolytinae) uses stem silhouette diameter as a visual host-finding cue. Environmental Entomology 42(4):743–750.

McRoberts, R.E. 2005. The enhanced Forest Inventory and Analysis Program. Pp. 1–10, *In* W.A. Bechtold and P.L. Patterson (Eds.). The enhanced Forest Inventory and Analysis Program—national sampling design and estimation procedures. General Technical Report SRS-80. US Department of Agriculture Forest Service, Southern Research Station, Asheville, NC. 85 pp.

Menard, R.D., S.R. Clarke, S.W. Fraedrich, and T.C. Harrington. 2016. First report of laurel wilt, caused by *Raffaelea lauricola*, on Redbay (*Persea borbonia*) in Texas. Plant Disease 100(7):1502.

Miles, P.D. 2016. Forest Inventory EVALIDator web-application version 1.6.0.03. US Department of Agriculture Forest Service, Northern Research Station, St. Paul, MN. Available online at http://apps.fs.fed.us/Evalidator/evalidator.jsp. Accessed 20 May 2016.

Moser, W.K., E.L. Barnard, R.F. Billings, S.J. Crocker, M.E. Dix, A.N. Gray, G.G. Ice, M. Kim, R. Reid, S.U. Rodman, and W.H. McWilliams. 2009. Impacts of nonnative invasive species on US forests and recommendations for policy and management. Journal of Forestry 107(6):320–327.

Nielsen, A.M., and L.K. Rieske. 2015. Potential host and range expansion of an exotic insect-pathogen complex: Simulating effects of Sassafras mortality from laurel wilt disease invasion in the central hardwoods region. The Journal of the Torrey Botanical Society 142(4):292–301.

North Carolina Forest Service. 2012. Laurel wilt continues to spread in southeastern North Carolina. Forest Health Notes Vol. 201201-LW. Available online at http://ncforestservice.gov/forest_health/pdf/FHN/FHN1201LW.pdf. Accessed 19 December 2016.

O'Connell, B.M., E.B. LaPoint, J.A. Turner, T. Ridley, S.A. Pugh, A.M. Wilson, K.L. Waddell, and B.L. Conkling. 2015. The Forest Inventory and Analysis database: Database description and user guide for phase 2 (version 6.02). Available online at http://www.fia.fs.fed.us/library/database-documentation/index.php. Accessed 18 May 2016.

Olatinwo, R., C. Barton, S.W. Fraedrich, W. Johnson, and J. Hwang. 2016. First report of Laurel Wilt, caused by *Raffaelea lauricola*, on Sassafras (*Sassafras albidum*) in Arkansas. Plant Disease 100(11):2331.

Oliver, C.D., and B.C. Larson. 1996. Forest Stand Dynamics. John Wiley and Sons, Inc., New York, NY. 520 pp.

Patterson, P.L., and G.A. Reams. 2005. Combining panels for forest inventory and analysis estimation. Pp. 69–74, *In* W.A. Bechtold and P.L Patterson (Eds.). The enhanced Forest Inventory and Analysis Program: National sampling design and estimation procedures. General Technical Report SRS-80. US Department of Agriculture Forest Service, Southern Research Station, Asheville, NC. 85 pp.

Riggins, J.J., S.W. Fraedrich, and T.C. Harrington. 2011. First report of laurel wilt caused by *Raffaelea lauricola* on Sassafras in Mississippi. Plant Disease 95(11):1479.

SAS Institute, Inc. 2010. SAS v. 9.3. Cary, NC.

Shearman, T.M., G.G. Wang, and W.C. Bridges. 2015. Population dynamics of Redbay (*Persea borbonia*) after laurel wilt disease: An assessment based on forest inventory and analysis data. Biological Invasions 17:1371–1382.

Shields, J., S. Jose, J. Freeman, M. Bunyan, G. Celis, D. Hagan, M. Morgan, E.C. Pieterson, and J. Zak. 2011. Short-term impacts of laurel wilt on Redbay (*Persea boronia* (L.) Spreng.) in a mixed evergreen–deciduous forest in northern Florida. Journal of Forestry 109(2):82–88.

Smith, J.A., T.J. Dreaden, A.E. Mayfield III, A. Boone, S.W. Fraedrich, and C. Bates. 2009. First report of laurel wilt disease, caused by *Raffaelea lauricola* on Sassafras in Florida and South Carolina. Plant Disease 93(10):1079.

Southern Regional Extension Forestry. 2016. Distribution of counties with laurel wilt as of April 7, 2016. Available online at http://southernforesthealth.net/fungi/laurel-wilt/distribution-map. Accessed 19 December 2016.

US Department of Agriculture (USDA) Forest Service, and US Department of Interior (USDI) Geological Survey. 2000. Forest cover types [map]. Available online at http://www.fia.fs.fed.us/library/maps/docs/forestcover.pdf. Accessed 5 August 2016.

USDA Forest Service. 2014. Forest Inventory and Analysis national core field guide. Volume 1: Field data collection procedures for phase 2 plots. Ver. 6.1. Available online at http://www.fia.fs.fed.us/library/field-guides-methods-proc/index.php. Accessed 18 May 2016. 433 pp.

Appendix 1. Forest types where Sassafras live trees, live saplings, live seedlings, or standing-dead trees are found in the eastern United States. x = present. Source: Miles (2016). Trees: DBH ≥ 12.7 cm, saplings: DBH ≥ 2.5 cm and DBH < 12.7 cm, and seedlings: DBH < 2.5 cm.

	Trees			
Forest type group/forest type	Live	Dead	Saplings	Seedlings
White/Red/Jack Pine				
Pinus resinosa Sol. es Aiton (Red Pine)	x		x	x
Pinus strobus L. (Eastern White Pine)	x	x	x	x
Eastern White Pine/Eastern Hemlock				x
Tsuga canadensis (L.) Carrière (Eastern Hemlock)	x			x
Longleaf/Slash Pine				
Pinus palustris Mill. (Longleaf Pine)	x		x	x
Pinus elliottii Engelm. (Slash Pine)	x	x	x	x
Loblolly/Shortleaf Pine				
Pinus taeda L. (Loblolly Pine)	x	x	x	x
Pinus echinata Mill. (Shortleaf Pine)	x	x	x	x
Pinus virginiana Mill. (Virginia Pine)	x	x	x	x
Pinus clausa (Chapm. ex Engelm.) Sarg. (Sand Pine)				x
Pinus serotina Michx. (Pond Pine)				x
Pinus rigida Mill. (Pitch Pine)	x	x	x	x
Pinus glabra Walter (Spruce Pine)				x
Other eastern softwoods				
Juniperus virginiana L. (Eastern Redcedar)	x	x	x	x
Exotic softwoods				
Pinus sylvestris L. (Scots Pine)	x		x	x
Other exotic softwoods				x
Picea abies (L.) H. Karst (Norway Spruce)		x		x
Introduced *Larix* (larch)	x	x	x	x
Oak/pine				
Eastern White Pine/Northern Red Oak/ *Fraxinus americana* L. (White Ash)	x	x	x	x
Eastern Redcedar/hardwood	x	x	x	x
Longleaf Pine/oak	x	x	x	x
Shortleaf Pine/oak	x	x	x	x
Virginia Pine/*Quercus falcata* Michx.(Southern Red Oak)	x	x	x	x
Loblolly Pine/hardwood	x	x	x	x
Slash Pine/hardwood		x	x	x
Other pine/hardwood	x	x	x	x
Oak/hickory				
Quercus stellata Wangenh. (Post Oak)/*Quercus marilandica* Muenchh.(Blackjack Oak)	x	x	x	x

Quercus montana Willd. (Chestnut Oak)	x	x	x	x
White Oak/red oak/hickory	x	x	x	x
Quercus alba L. (White Oak)	x	x	x	x
Quercus rubra L. (Northern Red Oak)	x	x	x	x
Yellow-poplar/White Oak/Northern Red Oak	x	x	x	x
Sassafras/Eastern Persimmon	x	x	x	x
Liquidambar styraciflua L. (American Sweetgum)/ Yellow-poplar	x	x	x	x
Quercus macrocarpa Michx. (Bur Oak)				x
Quercus coccinea Muenchh. (Scarlet Oak)	x	x	x	x
Liriodendron tulipifera L. (Yellow-poplar)	x	x	x	x
Juglans nigra L. (Eastern Black Walnut)	x		x	x
Robinia pseudoacacia L. (Black Locust)	x	x	x	x
Southern scrub oaks (various spp. of small oaks)	x		x	x
Chestnut Oak/*Quercus velutina* Lam. (Eastern Black Oak)/Scarlet Oak	x	x	x	x
Cherry/White Ash/Yellow-poplar	x	x	x	x
Elm/ash/Black Locust	x	x	x	x
Red Maple/oak	x	x	x	x
Mixed upland hardwoods	x	x	x	x
Oak/gum/cypress				
Quercus michauxii Nutt. (Swamp Chestnut Oak)/ *Quercus pagoda* Raf. (Cherrybark Oak)	x	x	x	x
Sweetgum/*Quercus texana* Buckley (Nuttall's Oak)/ *Quercus phellos* L. (Willow Oak)	x	x	x	x
Quercus lyrata Walter (Overcup Oak)/*Carya aquatica* (F. Michx.) Nutt. (Water Hickory)	x	x	x	x
Chamaecyparis thyoides (L.) Britton, Sterns, & Poggenb. (Atlantic White Cedar)				x
Taxodium distichum (L.) Rich. (Baldcypress)/*Nyssa aquatica* L. (Water Tupelo)		x	x	
Magnolia virginiana L. (Sweetbay)/*Nyssa biflora* Watler (Swamp Tupelo)/Red Maple	x	x	x	x
Fraxinus nigra Marshall (Black Ash)/*Ulmus americana* L. (American Elm)/Red Maple	x	x	x	x
Betula nigra L. (River Birch)/*Platanus* (sycamore)	x	x	x	x
Populus (cottonwood)	x		x	x
Salix (willow)	x		x	x
Sycamore/ *Carya illinoinensis* (Wangenh.) K.Koch (Pecan)/American Elm	x	x	x	x
Celtis laevigata Willdenow (Sugarberry)/*Celtis occidentalis* L. (Hackberry)/elm/*Fraxinus pennsylvanica* Marshall (Green Ash)	x	x	x	x
Acer saccharinum L. (Silver Maple)/American Elm	x		x	x
Red Maple/lowland	x	x		x
Cottonwood/willow	x	x	x	x

Maple/beech/birch				
Sugar Maple/beech/*Betula alleghaniensis* Britt. (Yellow Birch)	x	x	x	x
Prunus serotina Ehrh. (Black Cherry)	x	x	x	x
Hard maple (mulitple spp.)/*Tilia americana* L. (Basswood)	x	x	x	x
Red Maple/upland	x	x		x
Aspen/birch				
Populus (aspen)	x	x	x	x
Betula populifolia Marsh. (Gray Birch)			x	
Other hardwoods				
Other hardwoods	x	x	x	x
Exotic hardwoods				
Paulownia	x			x
Other exotic hardwoods	x	x	x	x

Appendix 2. Ecoregion sections and their intersecting states where Sassafras trees, saplings, seedlings, or the Sassafras/Eastern Persimmon forest type are found in the eastern United States.

	Ecoregion section	Intersecting state
211F	Northern Glaciated Allegheny Plateau	NY, PA
211G	Northern Unglaciated Allegheny Plateau	NY, PA
212H	Northern Lower Peninsula	MI
221A	Lower New England	CT, ME, MA, NH, NJ, NY, PA, RI, VT
221B	Hudson Valley	NJ, NY, PA, VT
221D	Northern Appalachian Piedmont	DE, MD, NJ, NY, PA, VA
221E	Southern Unglaciated Allegheny Plateau	KY, OH, PA, WV
221F	Western Glaciated Allegheny Plateau	OH, PA, NY
221H	Northern Cumberland Plateau	KY, TN
221J	Central Ridge and Valley	GA, TN, VA
222H	Central Till Plains-Beech-Maple	IL, IN, OH
222I	Erie and Ontario Lake Plain	OH, PA, NY
222J	South Central Great Lakes	IL, IN, MI, OH
222K	Southwestern Great Lakes Morainal	IL, IN, WI
222U	Lake Whittlesey Glaciolacustrine Plain	IN, MI, OH
223A	Ozark Highlands	AR, IN, KS, MO, OK
223B	Interior Low Plateau-Transition Hills	IN, KY
223D	Interior Low Plateau-Shawnee Hills	IL, IN, KY
223E	Interior Low Plateau-Highland Rim	AL, KY, TN
223F	Interior Low Plateau-Bluegrass	IN, KY, OH
223G	Central Till Plains-Oak Hickory	IL, IN
231A	Southern Appalachian Piedmont	AL, GA, NC, SC
231B	Coastal Plains-Middle	AL, GA, MS, TN
231C	Southern Cumberland Plateau	AL, GA, TN
231D	Southern Ridge and Valley	AL, GA, TN
231E	Mid Coastal Plains-Western	AR, LA, OK, TX
231G	Arkansas Valley	AR, OK
231H	Coastal Plains-Loess	IL, KY, LA, MS, TN
231I	Central Appalachian Piedmont	NC, SC, VA
232A	Northern Atlantic Coastal Plain	DE, MD, NJ, PA, VA
232B	Gulf Coastal Plains and Flatwoods	AL, GA, FL, LA, MS
232C	Atlantic Coastal Flatwoods	GA, FL, NC, SC
232E	Louisiana Coastal Prairie and Marshes	LA, MS, TX
232F	Coastal Plains and Flatwoods-Western Gulf	LA, TX
232G	Florida Coastal Lowlands-Atlantic	FL
232H	Middle Atlantic Coastal Plains and Flatwoods	DE, MD, NC, VA
232I	Northern Atlantic Coastal Flatwoods	NC, VA
232J	Southern Atlantic Coastal Plains and Flatwoods	FL, GA, NC, SC
232K	Florida Coastal Plains Central Highlands	FL
232L	Gulf Coastal Lowlands	AL, FL, LA, MS
234A	Southern Mississippi Alluvial Plain	AR, LA, MS
234D	White and Black River Alluvial Plains	AR, IL, KY, LA, MS, MO, TN

234E	Arkansas Alluvial Plains	AR, LA
251C	Central Dissected Till Plains	IL, IA, KS, MO, NE, SD
251D	Central Till Plains and Grand Prairies	IL, IN
251E	Osage Plains	KS, MO, OK
251F	Flint Hills	KS, OK
255A	Cross Timbers and Prairie	KS, OK, TX
255B	Blackland Prairie	TX
255C	Oak Woods and Prairie	TX
255D	Central Gulf Prairie and Marshes	TX
332F	South Central and Red Bed Plains	KS, OK, TX
M211B	New England Piedmont	MA, NH, VT
M211C	Green-Taconic-Berkshire Mountains	CT, NY, MA, VT
M221A	Northern Ridge and Valley	MD, NJ, PA, TN, VA, WV
M221B	Allegheny Mountains	MD, PA, VA, WV
M221C	Northern Cumberland Mountains	KY, VA, WV
M221D	Blue Ridge Mountains	GA, MD, NC, PA, SC, TN, VA, WV
M223A	Boston Mountains	AR, OK
M231A	Ouachita Mountains	AR, OK