

Short-Term Impacts of Laurel Wilt on Redbay (*Persea borbonia* [L.] Spreng.) in a Mixed Evergreen–Deciduous Forest in Northern Florida

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ABSTRACT

We examined the immediate effects of laurel wilt on redbay (*Persea borbonia* [L.] Spreng.) and stand-level characteristics in a mixed evergreen-deciduous forest at Etoniah Creek State Forest in Florida. Percent mortality of redbay in the overstory, sapling, and seedling layers were 100%, 30.2%, and 1.8%, respectively, in the year after the first signs of infection were observed. The diameter distribution of redbay shifted from a reverse “J” pattern to a distribution where the only remaining living stems were <4-in. dbh. Mortality of redbay also resulted in significant reductions in overstory redbay importance values and stand-level density and basal area. Our results suggest that (1) laurel wilt has a more pronounced effect on overstory redbays than smaller stems and (2) redbay mortality caused by laurel wilt can result in modest but significant changes in stand structure.

Keywords: Etoniah Creek State Forest, exotic species, hardwood hammocks, nonnative species, *Raffaelea lauricola*, redbay ambrosia beetle, southern mixed hardwoods, *Xyleborus glabratus*

It is widely acknowledged that the introduction of nonnative species has altered ecosystems worldwide (Wilcove et al. 1998, Mack et al. 2000, Myers et al. 2000, Chornesky and Randall 2003, Molnar et al. 2008). Such introductions have led

to subsequent reductions or complete losses of native taxa (Jose et al. 2002, Poland and McCullough 2006) or altered disturbance regimes that favor the nonnative species (Brooks et al. 2004). For example, Wilcove et al. (1998) found that competition with or

predation from nonnative species was the second-most important threat to 1,880 native species in the United States. Habitat destruction was the only factor that impacted a higher percentage of these native species (Wilcove et al. 1998). In some cases, losses or declines of native taxa may translate into a loss of ecosystem services (Daily et al. 1997), many of which have likely not been discovered (Burton et al. 1992). Furthermore, there is a growing concern about the economic losses that are incurred from the introduction of nonnative species (Pimental et al. 2000, Costello and McAusland 2003). For example, Pimental et al. (2000) estimated that the damage caused by nonnative organisms in the United States leads to economic losses of approximately \$137 billion/year. It has also been estimated that nonnative forest pathogens alone cause forest

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product losses equivalent to approximately \$2 billion/year (Pimental et al. 2000).

In forested ecosystems, the effects of non-native organisms have been mixed. For example, Morin et al. (2007) reported that beech bark disease (BBD) had invaded most regions where American beech (*Fagus grandifolia* Ehrh.) was a dominant species in the forest. However, these same authors found that despite increased mortality of individual American beech stems after invasion of BBD, the overall volume of American beech had increased in these regions (Morin et al. 2007). Herrick and Gansner (1988) found that damage caused by the gypsy moth (*Lymantria dispar*) caused reductions in volume and stocking (including a reduced oak [*Quercus* spp.] component) in forests in northeastern and central Pennsylvania. Orwig and Foster (1998) examined eight eastern hemlock (*Tsuga canadensis* [L.] Carrière) stands in southeastern Connecticut that were invaded by the nonnative hemlock woolly adelgid (*Adelgis tsugae*). These authors found that damage caused by the hemlock woolly adelgid resulted in a dramatic reduction of eastern hemlock stems that were present before invasion, as well as a scarcity of regeneration (i.e., seedlings and saplings) after invasion (Orwig and Foster 1998). Dogwood anthracnose, a disease caused by the nonnative fungus *Discula destructiva*, has been shown to rapidly kill flowering dogwood (*Cornus florida* L.) trees in the eastern hardwood forests and dogwood mortality has exceeded 90% in some forest types (Hires and Evans 1997, Holzmueller et al. 2006).

Laurel wilt is a vascular disease that is currently causing the widespread mortality of redbay (*Persea borbonia* [L.] Spreng.; Figure 1) throughout forests in the southeastern United States (Fraedrich et al. 2007, 2008; Mayfield et al. 2008a). This disease is caused by a fungus (*Raffaelea lauricola*) that is transported by the nonnative Asian ambrosia beetle, *Xyleborus glabratus* Eichhoff (Hunula et al. 2008). It is believed that *R. lauricola* is also nonnative and was brought to the United States along with the Asian ambrosia beetle (Harrington et al. 2008). Redbay mortality due to laurel wilt was first detected in South Carolina in 2003 (although the Asian ambrosia beetle was first discovered in Georgia in 2002; Fraedrich et al. 2007). Since its initial detection, laurel wilt has spread throughout many coastal plain counties of South Carolina and Georgia, as well as peninsular Florida (Mayfield et al. 2008a; Figure 2). This widespread mortality is of concern not only because of the aesthetic



Figure 1. Picture of young redbay (*Persea borbonia* [L.] Spreng.) stems. (Photo by Chris Evans, River to River CWMA, www.Bugwood.org. Photo obtained from Forestry Images: Forest Health, Natural Resources, & Silviculture Images at www.forestryimages.org/.)

and economic losses associated with the loss of ornamental redbays (Mayfield et al. 2008a), but also because redbay provides food and habitat for many species of wildlife in the forests of the Southeast (Landers et al. 1979, Brendemuehl 1990, Lederhouse et al. 1991, Mayfield et al. 2008a). Furthermore, redbay wood is used locally for cabinetmaking, interior finishing, and boatbuilding (Brendemuehl 1990).

Finally, research has shown that other woody plants in the Lauraceae family are susceptible to infection by the laurel wilt fungus, including swamp bay (*Persea palustris* [Raf.] Sarg.; Mayfield et al. 2008a), sassafras (*Sassafras albidum* [Nutt.] Nees; Fraedrich et al. 2008), southern spicebush (*Lindera melissifolia* [Walter] Blume; Fraedrich et al. 2008), pondspice (*Litsea aestivalis* [L.] Fernald; Fraedrich et al. 2008), camphortree (*Cinnamomum camphora* [L.] J. Presl; Smith et al. 2009), and the commercially important avocado (*Persea americana* Mill.; Mayfield et al. 2008b, 2008c). Should laurel wilt begin to cause widespread mortalities of sassafras, subsequent impacts on forests may be observed throughout the entire eastern United States (Figure 3). Research aimed at understanding the impacts of laurel wilt is therefore of the utmost importance if land managers are to develop strategies to counteract the effects of this disease.

We investigated the immediate impacts of laurel wilt on redbay in a mixed evergreen-deciduous forest in northern Putnam County, in Northeast Florida. Laurel wilt was first detected in Putnam County in 2007 (Mayfield et al. 2008a), thus presenting an opportunity to study the short-term impacts of this disease in this region. Although several studies have examined the

impact of laurel wilt at the species level (Fraedrich et al. 2008, Hanula et al. 2008, Mayfield et al. 2008b, Smith et al. 2009), it remains unclear how laurel wilt alters stand-level characteristics of forests. The specific objectives of this study were to examine the short-term impacts of laurel wilt on (1) the percent mortality, diameter distribution, and relative importance of redbay; and (2) stand-level characteristics (i.e., density and basal area [BA]). This is the first documented report showing the impact of laurel wilt at the stand level.

Methods

Study Area

The study area is in a mixed evergreen-deciduous forest located at Etoniah Creek State Forest in Putnam County, in Northeast Florida (29°N, 81°W). The terrain is characterized by knolls, depressions, floodplains, and drainageways on marine terraces that overly sedimentary bedrock (ranging in age from Paleozoic to recent; Readle 1990). Soil types consist of a mix of fine sands, sands, and mucks, with drainage classes ranging from moderately well drained (e.g., Centenary fine sand) to very poorly drained (e.g., Hontoon muck; Readle 1990). This area receives an average rainfall of 55.9 in., with approximately 60% of this falling between June and September in the form of afternoon and evening convection thunderstorms (Readle 1990). Mean temperatures in this area range from a daily minimum of 39.9°F in the winter to a daily maximum of 88.9°F in the summer (Readle 1990).

The disturbance history of this mixed evergreen-deciduous forest is characterized mainly by intensive timber harvesting that took place more than 40 years ago, with little

Distribution of Counties with Laurel Wilt Disease* by year of Initial Detection

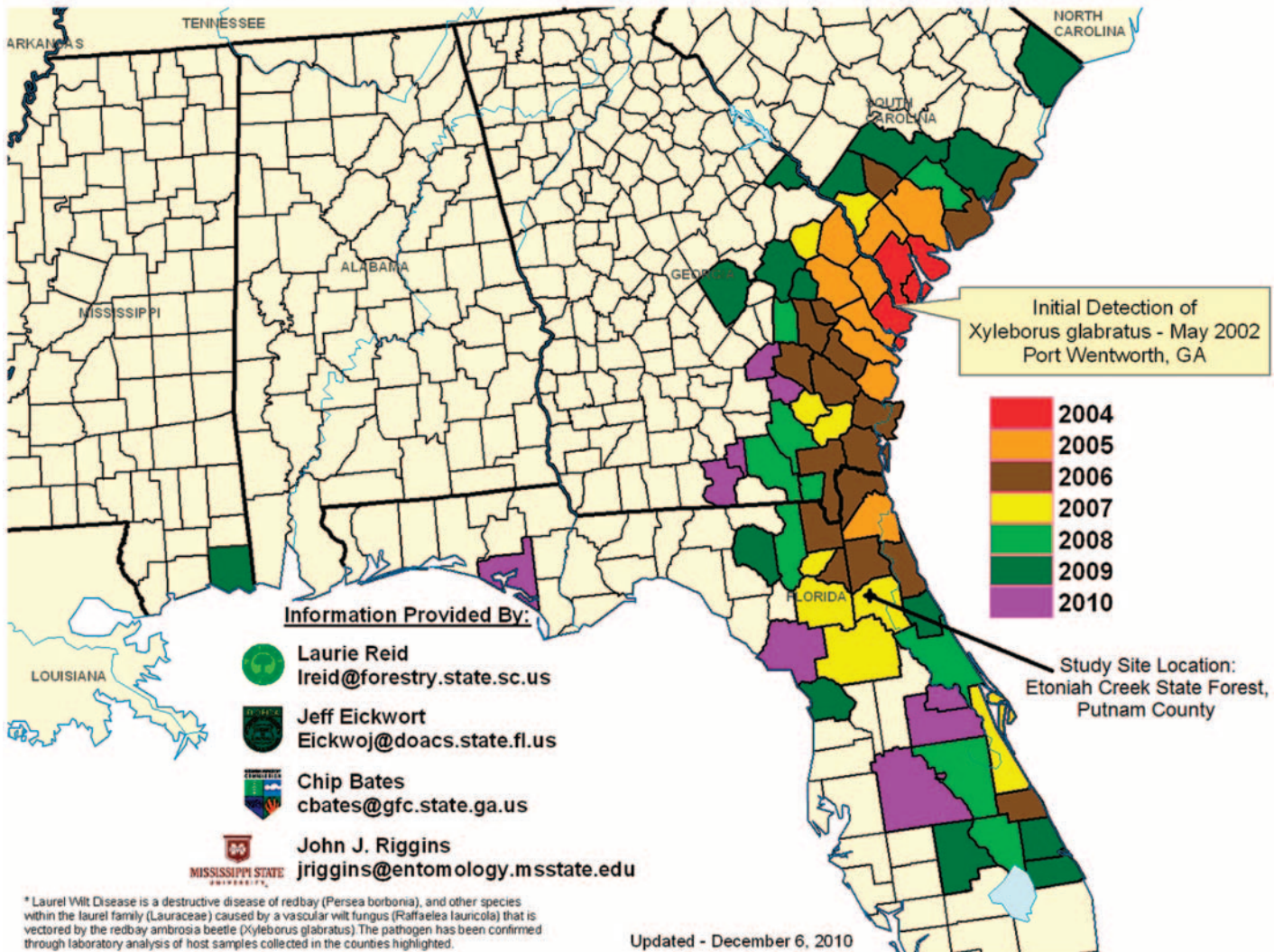


Figure 2. Current distribution of laurel wilt throughout the southeastern United States (the map indicates year of initial detection by county). (Figure obtained from US Forest Service Southern Research Station at www.fs.fed.us/r8/foresthealth/laurelwilt/dist_map.shtml.)

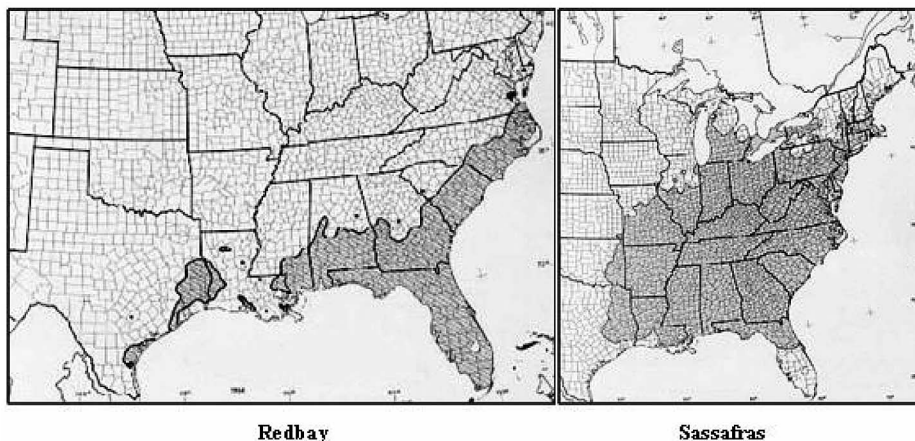


Figure 3. Comparison of ranges of redbay (*Persea borbonia* [L.] Spreng.; left image) and sassafras (*Sassafras albidium* [Nutt.] Nees; right image), indicating the potential range of impact from laurel wilt throughout the eastern United States. (Redbay range map was obtained from Brendemuehl (1990). Sassafras range map was obtained from Griggs (1990).)

to no management activity in recent decades. Natural disturbances have been limited to small to intermediate-scale windthrow events. No evidence of fire was observed.

Study Design and Data Collection

In 2007, we selected nine, 5-ac plots that contained redbay and/or that were representative of mixed evergreen-deciduous forests where redbay typically occurs, as described by Brendemuehl (1990). In each of the 9 plots we established 20, 0.1-ac subplots (hereafter referred to as overstory subplots) using a systematic grid design (5 × 4 plot grid with overstory subplots spaced 105 ft from subplot center to subplot center). In 2007–2008, we recorded the diameters of overstory stems (living woody stems ≥4-in. dbh) by species in each overstory subplot. In 2009 we revisited the overstory subplots and recorded which redbay trees had

died from laurel wilt. Only redbay trees that were alive during the 2007–2008 inventory were considered (mortalities were not observed for species other than redbay). Diameters were not remeasured for any species in 2009. We also nested a smaller circular plot (radius of 6.5 ft; hereafter referred to as understory subplot) at the center of each overstory subplot. Within each understory subplot, we recorded the number of sapling-layer stems (living woody stems <4-in. dbh and ≥4 ft tall) and seedling-layer stems (living woody stems <4 ft tall) by species (in some cases only to genus). For redbay, we also counted the number of sapling-layer and seedling-layer stems that were dead due to laurel wilt. In the sapling layer, no mortalities were observed for species other than redbay. Sapling-layer and seedling-layer data were collected only in 2009. Symptoms of laurel wilt were diagnosed using one or more of the following criteria—drooping foliage with reddish, purplish, or brownish coloration; dark streaking in the sapwood; and compacted strands of sawdust protruding from the main stem or branches (Mayfield et al. 2008a). Nomenclature of plant names follows that of the USDA Plants Database (USDA Natural Resources Conservation Service 2009).

Data Analyses

We calculated mean stems/acre, relative density, and relative frequency for overstory and sapling-layer stems by species or genus in each of the nine study plots. For overstory stems, we calculated mean BA/acre (square feet per acre) and relative dominance (i.e., relative BA) by species and plot. Mean importance values (IV) by taxon were also calculated for overstory ($IV = [\text{relative density} + \text{relative dominance} + \text{relative frequency}]/3$) and sapling-layer stems ($IV = [\{\text{relative density} + \text{relative frequency}\}/2]$). Mean stems/acre, BA/acre, and IVs were calculated based on two conditions—(1) before redbay mortalities caused by laurel wilt (i.e., data including all redbay stems dead and alive) and (2) after infected redbays had died (i.e., data excluding dead redbay stems). We used the 2007–2008 data for overstory calculations based on all stems and the 2009 data for calculations that excluded dead redbays. As stated previously, only living overstory stems were recorded in 2007–2008. Therefore, the number of redbay stems that died from laurel wilt (as documented in 2009) represents a subset of the living redbay stems from 2007 to 2008. The 2009 data were also used for sapling-layer calculations that excluded dead redbay stems. However, because we lacked sapling-layer data before 2009, we

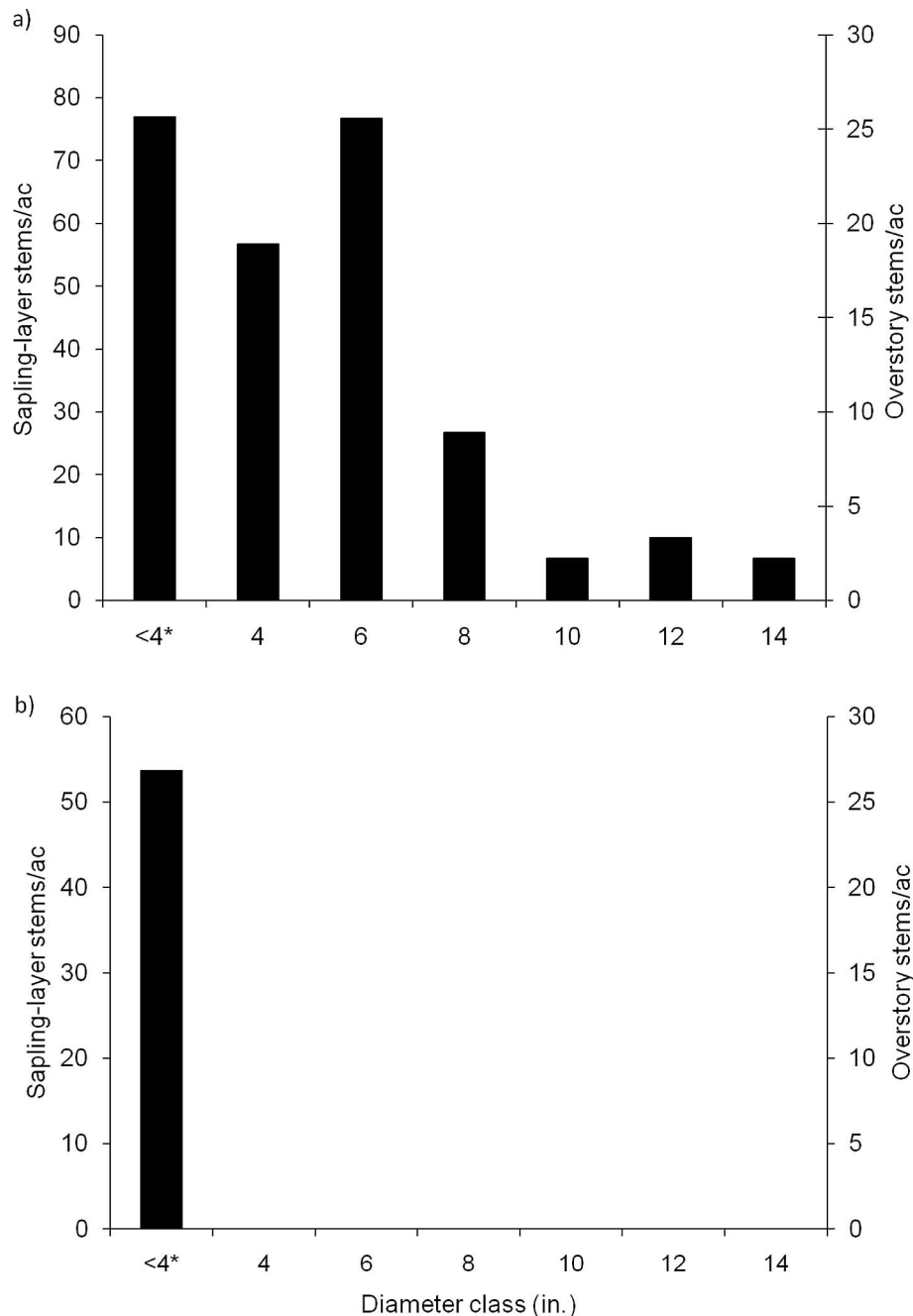


Figure 4. Diameter distribution of redbay (a) before mortalities caused from laurel wilt (data including all redbay stems) and (b) excluding redbay stems that died from laurel wilt. Asterisk denotes redbay stems in the sapling layer (stems of <4-in. dbh and >4 ft tall; stems/acre are on the left axis). Stems of ≥4-in. dbh were classified as overstory (stems/acre are on the right axis).

assumed that any redbay saplings recorded as dead in 2009 were alive for calculations based on all stems (i.e., before redbay mortalities). Seedlings were excluded from all calculations because it was unclear how many seedlings colonized the plots between sampling periods.

To gain insights into the impacts of laurel wilt, we examined the immediate, stand-level changes that resulted from redbay mortality. More specifically, we used paired comparisons

to examine changes in overstory stems/acre, BA/acre, sapling-layer stems/acre, and redbay IVs (overstory and saplings) by comparing calculations based on all stem data with calculations based on data where dead redbay stems were excluded. A paired *t*-test ($n = 9, \alpha = 0.05$) was used when differences between pairs were normally distributed (assessed using Shapiro and Wilk *W* test); otherwise a Wilcoxon paired-sample test was used ($n = 9, \alpha = 0.05$;

Table 1. Mean (± 1 SE) IVs for overstory species (woody stems ≥ 4 in. dbh; IV = [relative density + relative dominance + relative frequency]/3) before redbay mortalities caused by laurel wilt (including all redbay stems) and excluding redbay stems killed by laurel wilt, across nine, 5-ac plots at Etoniah Creek State Forest.

Species	IV	
	Including all redbay stems ^a	Excluding dead redbay stems ^b
Loblolly Pine (<i>Pinus taeda</i> L.)	18.22 \pm 5.61	18.46 \pm 5.62
Water Oak (<i>Quercus nigra</i> L.)	16.95 \pm 3.81	17.25 \pm 3.79
Sweetbay (<i>Magnolia virginiana</i> L.)	13.81 \pm 3.92	14.37 \pm 4.14
Sweetgum (<i>Liquidambar styraciflua</i> L.)	10.94 \pm 1.66	11.24 \pm 1.68
Darlington Oak (<i>Quercus hemisphaerica</i> Bartram ex Willd.)	7.33 \pm 3.21	7.40 \pm 3.22
Blackgum (<i>Nyssa sylvatica</i> Marsh.)	5.56 \pm 1.96	5.84 \pm 2.09
Sand Live Oak (<i>Quercus geminata</i> Small)	5.54 \pm 2.69	5.62 \pm 2.74
Red Maple (<i>Acer rubrum</i> L.)	4.86 \pm 2.37	5.15 \pm 2.54
Pignut Hickory (<i>Carya glabra</i> [Mill.] Sweet)	3.24 \pm 1.95	3.28 \pm 1.97
American Hornbeam (<i>Carpinus caroliniana</i> Walter)	3.01 \pm 1.40	3.10 \pm 1.41
Loblolly Bay (<i>Gordonia lasianthus</i> [L.] Ellis)	2.56 \pm 1.01	2.68 \pm 1.06
Redbay (<i>Persea borbonia</i> [L.] Spreng.)	2.48 \pm 0.77 ^a	0.00 \pm 0.00 ^b
Live Oak (<i>Quercus virginiana</i> Mill.)	2.20 \pm 1.15	2.24 \pm 1.17
Southern Magnolia (<i>Magnolia grandiflora</i> L.)	1.50 \pm 0.70	1.54 \pm 0.71
Rusty Staggerbush (<i>Lyonia ferruginea</i> [Walter] Nutt.)	0.39 \pm 0.33	0.41 \pm 0.34
Black Cherry (<i>Prunus serotina</i> Ehrh.)	0.26 \pm 0.17	0.27 \pm 0.18
Laurel Oak (<i>Quercus laurifolia</i> Michx.)	0.22 \pm 0.15	0.22 \pm 0.15
Saw Palmetto (<i>Serenoa repens</i> [Bartram] Small)	0.18 \pm 0.18	0.18 \pm 0.18
Southern Sugar Maple (<i>Acer barbatum</i> Michx.)	0.15 \pm 0.15	0.16 \pm 0.16
American Holly (<i>Ilex opaca</i> Aiton)	0.11 \pm 0.11	0.12 \pm 0.12
Bluejack Oak (<i>Quercus incana</i> Bartram)	0.09 \pm 0.09	0.09 \pm 0.09
Chapman Oak (<i>Quercus chapmanii</i> Sarg.)	0.09 \pm 0.09	0.09 \pm 0.09
Wax Myrtle (<i>Morella cerifera</i> [L.] Small)	0.09 \pm 0.09	0.09 \pm 0.09
Cabbage Palmetto (<i>Sabal palmetto</i> [Walter] Lodd. ex Schult.&Schult. f.)	0.07 \pm 0.07	0.07 \pm 0.07
Red Mulberry (<i>Morus rubra</i> L.)	0.06 \pm 0.06	0.06 \pm 0.06
Flowering Dogwood (<i>Cornus florida</i> L.)	0.05 \pm 0.05	0.06 \pm 0.06

Different letters indicate a significant reduction in the IV of redbay using a paired *t*-test ($\alpha = 0.05$). Mortalities of species other than redbay were not observed.

^a Reflects the 2007–2008 data collection period, when all redbay stems inventoried were documented as alive.

^b Reflects the 2009 data collection period, when plots were re-visited and dead redbay stems were documented.

Zar 1999). All statistical analyses were performed using JMP (SAS Institute 2007).

For redbay stems only, we calculated percent mortality (caused by laurel wilt) for each stratum (overstory, sapling, and seedling) using the formula mortality (%) = ([number of dead redbay stems]/[number of dead and living redbay stems] * 100). Only the 2009 data were used for this calculation. We also examined how the diameter distribution of redbay changed after mortalities caused by laurel wilt. This was done by comparing the diameter distribution of all redbay stems (living and dead) to the diameter distribution of living redbay stems. Only overstory and sapling-layer stems were included in diameter distributions.

Results

Across all sample plots and both data collection periods, we recorded 55 redbay stems in the overstory, 43 redbay stems in the sapling layer, and 114 redbay stems in the seedling layer. All 55 redbay stems in the overstory were dead by 2009 (100% mortality). Redbay sapling and seedling percent mortalities were 30.2% (13 dead stems) and 1.8% (2 dead stems), respectively. Before mortalities from

laurel wilt, redbay exhibited a broad reverse “J”-shaped diameter distribution, with approximately 76 saplings/ac and 61 overstory stems/ac (Figure 4). However, subtracting all redbay stems that died from laurel wilt resulted in approximately 54 saplings/ac and a complete loss of redbay stems in diameter classes ≥ 4 in. (Figure 4). When all stems were considered, redbay exhibited the 12th-highest IV in the overstory (2.48 \pm 0.77; Table 1) and the 8th-highest IV in the sapling layer (7.22 \pm 4.07; Table 2). Excluding redbay stems that died from laurel wilt resulted in a significant decrease in IVs of redbay in the overstory (paired *t*-test, $P = 0.01$ and $n = 9$; Table 1) but not the sapling layer (Wilcoxon paired-sample test, $P = 0.06$ and $n = 9$; Table 2).

When all species were included, mean overstory stems/acre and BA/acre were 136 \pm 6.0 stems/ac and 93.9 \pm 3.3 ft²/ac, respectively. Excluding dead redbay stems resulted in slight but significant reductions in mean stems/acre (132.9 \pm 6.5 stems/ac; paired *t*-test, $P = 0.02$ and $n = 9$) and BA/acre (93.0 \pm 3.3 ft²/ac; paired *t*-test, $P = 0.02$ and $n = 9$). Conversely, the reduction

of stems/acre in the sapling layer was not significant (Wilcoxon paired-sample test, $P = 0.06$ and $n = 9$).

Discussion and Conclusions

Our results suggest that in just 1 year after initial detection, laurel wilt can lead to a drastic reduction of redbay stems, with a more pronounced effect in the overstory layer. Symptoms of laurel wilt were first detected in the study area in 2007 (Shibu Jose, University of Florida, personal observation, Winter 2007) and by 2009, this disease had killed 100% of the redbays in the overstory stratum. However, redbay stems <4-in. dbh appeared to be initially less susceptible to laurel wilt. Mayfield et al. (2008a) also suggested that redbay seedlings and small sprouts did not appear to be affected by laurel wilt. Similarly, Fraedrich et al. (2008) found that redbay mortality rates caused from laurel wilt were much higher in stems of ≥ 1 -in. dbh than stems <1-in. dbh at field sites throughout the southeastern United States. However, these same authors found that Asian ambrosia beetles are capable of causing high mortality rates in redbay seedlings (Fraedrich et al. 2008). In one experiment, 90% of redbay

Table 2. Mean (± 1 SE) IVs for sapling-layer taxa (woody stems of <4-in. dbh and >4 ft tall; IV = [relative density + relative frequency]/2) including all redbay stems and excluding dead redbay stems across nine, 5-ac plots at Etoniah Creek State Forest.

Species	IV	
	Including all redbay stems ^a	Excluding dead redbay stems ^b
Coastal Doghobble (<i>Leucothoe axillaris</i> [Lam.] D. Don)	16.63 \pm 5.36	16.86 \pm 5.39
Water Oak (<i>Quercus nigra</i> L.)	12.62 \pm 3.34	12.83 \pm 3.35
Staggerbush (<i>Lyonia</i> spp.)	7.98 \pm 2.83	8.04 \pm 2.86
Virginia Sweetspire (<i>Itea virginica</i> L.)	7.88 \pm 4.18	8.11 \pm 4.29
Loblolly Bay (<i>Gordonia lasianthus</i> [L.] Ellis)	7.55 \pm 3.97	7.89 \pm 4.12
Sweetbay (<i>Magnolia virginiana</i> L.)	7.41 \pm 1.91	7.48 \pm 1.91
Sweetgum (<i>Liquidambar styraciflua</i> L.)	7.28 \pm 2.19	7.49 \pm 2.23
Redbay (<i>Persea borbonia</i> [L.] Spreng.) ^c	7.22 \pm 4.07	5.42 \pm 3.36
American Hornbeam (<i>Carpinus caroliniana</i> Walter)	5.48 \pm 3.55	5.50 \pm 3.55
Deerberry (<i>Vaccinium stamineum</i> L.)	4.51 \pm 1.44	4.61 \pm 1.47
Farkleberry (<i>Vaccinium arboreum</i> Marsh.)	4.28 \pm 1.83	4.47 \pm 1.95
Saw Palmetto (<i>Serenoa repens</i> [Bartram] Small)	3.10 \pm 2.88	3.10 \pm 2.88
Darlington Oak (<i>Quercus hemisphaerica</i> Bartram ex Willd.)	1.89 \pm 1.89	1.89 \pm 1.89
Blackberry (<i>Rubus</i> spp.)	1.39 \pm 1.39	1.42 \pm 1.42
Hog Plum (<i>Prunus umbellata</i> Elliot)	0.80 \pm 0.80	0.81 \pm 0.81
Pignut Hickory (<i>Carya glabra</i> [Mill.] Sweet)	0.76 \pm 0.51	0.81 \pm 0.55
Southern Magnolia (<i>Magnolia grandiflora</i> L.)	0.54 \pm 0.54	0.54 \pm 0.54
Unknown	0.53 \pm 0.53	0.53 \pm 0.53
Dahoon (<i>Ilex cassine</i> L.)	0.46 \pm 0.46	0.47 \pm 0.47
American Holly (<i>Ilex opaca</i> Aiton)	0.36 \pm 0.36	0.37 \pm 0.37
Laurel Oak (<i>Quercus laurifolia</i> Michx.)	0.36 \pm 0.36	0.37 \pm 0.37
Flowering Dogwood (<i>Cornus florida</i> L.)	0.33 \pm 0.33	0.33 \pm 0.33
Loblolly Pine (<i>Pinus taeda</i> L.)	0.33 \pm 0.33	0.33 \pm 0.33
Wax Myrtle (<i>Morella cerifera</i> [L.] Small)	0.32 \pm 0.32	0.32 \pm 0.32

Mortalities of species other than redbay were not observed.

^a Redbay saplings recorded as dead in 2009 were assumed to be alive for calculations reflecting importance values prior to redbay mortalities caused from laurel wilt.

^b Reflects the 2009 data collection period; redbay stems documented as dead were excluded from calculations.

^c No significant difference was found between mean ranks of importance values using Wilcoxon paired-sample test ($P = 0.06$; $n = 9$).

seedlings challenged with Asian ambrosia beetles were infected and subsequently killed from laurel wilt (Fraedrich et al. 2008). In a trapping experiment in South Carolina and Georgia, Hanula et al. (2008) found that trap catches of Asian ambrosia beetles were higher in locations where mature redbay trees had not been depleted when compared with locations where mature redbays had all been killed by laurel wilt. Thus, it appears that the population level of Asian ambrosia beetles in a forest is correlated with the quantity of larger redbay stems. However, it remains unclear at which size a redbay becomes more susceptible to being infected. Furthermore, once larger redbays are depleted as a host, will the mortality rates of smaller stems increase? These are questions that should be answered so that forest managers can more effectively focus management techniques to restore redbay.

Redbay mortality caused from laurel wilt may result in a noticeable shift in forest characteristics at the stand level. Excluding redbay stems that died from laurel wilt equated to an immediate 2–3% reduction in stems/acre and BA/acre of living stems across all species. These reductions were enough to result in significant decreases in IVs of redbay in the overstory, but not the sapling layer. It is important to note that we did not quantify the growth of residual

stems after redbay mortalities (diameters of trees were not remeasured in 2009). It is possible that the loss of redbay may have caused a thinning effect by which BA growth of residual stems offsets the losses of live BA from redbay mortalities. However, all of the redbay trees died in a short time span and nearly all of these stems were still standing in 2009. Thus, it is more likely that growth and recruitment of residual stems were less than the losses due to redbay mortality, leading to a stand-level reduction in stems/acre and BA/acre. Our data represent the immediate loss of living stems/acre and the resultant BA/acre because of redbay mortality. The openings created where overstory redbays have died will eventually provide growing space for advanced regeneration to recruit into the overstory layers and/or for the colonization of seedlings, shrubs, herbaceous plants, and other taxa. However, given the current decline of redbay from laurel wilt, it is unlikely that redbay will reoccupy such openings unless Asian ambrosia beetle populations decline to a level where they are not transporting laurel wilt throughout the entire forest stand.

In other forests, such reductions caused from laurel wilt will depend on how much growing space is occupied by redbay, which will vary by habitat type (Brendemuehl 1990,

Van Deelen 1991). For example, in low hammocks or bayheads where redbay is the dominant species (Klukas 1973, Van Deelen 1991), mortalities due to laurel wilt would undoubtedly result in higher reductions of stand-level stems/acre and BA/acre when compared with our study area.

Hanula et al. (2008) suggest that Asian ambrosia beetle populations do show a dramatic decline after suitable host material is depleted. In circumstances where beetles have depleted the host material, there may be potential for forest managers to successfully implement restoration strategies aimed at restoring redbay. However, it remains unclear whether Asian ambrosia beetle populations will recover and/or recolonize sites where redbays have been restored; this merits additional investigation.

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