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Distribution and Spread of Laurel Wilt Disease in Georgia *2006-08 Survey and Field Observations*



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Introduction

Laurel wilt (LW), caused by the fungus *Raffaelea lauricola*, is a new disease of plants in the Lauraceae family in the United States, vectored by an introduced Asian ambrosia beetle, *Xyleborus glabratus* (Fraedrich et al. 2008, Harrington et al. 2008). Since the capture of the first *X. glabratus* in a monitoring trap near the Port of Savannah and the first reports of dying redbay trees (*Persea borbonia*) near Savannah in 2003 and 2004, this disease has spread rapidly through the abundant redbay in the maritime and coastal plain forests northward in South Carolina and south well into Florida, killing most of the large redbay trees in its path. Other plants in the laurel family known to be susceptible to varying degrees include: sassafras (*Sassafras albidum*), avocado (*Persea americana*), pondspice (*Litsea aestivalis*), and pondberry (*Lindera melissifolia*), the latter two being federally listed as threatened and endangered species, respectively (Fraedrich et al. 2008).

This exotic disease episode is particularly noteworthy because it is caused by a previously unknown pathogen vectored by an ambrosia beetle that was not expected to be a serious threat to forests or wood products in the U.S. Yet in less than 10 years, it has essentially eliminated redbay from a large portion of the South Atlantic Coastal Plain and maritime forests. This disease may continue to expand throughout coastal plain forests from Virginia to Texas and is a threat to the avocado industry in south Florida and elsewhere. Ambrosia beetles generally attack dead and dying hosts and do not vector important diseases. The redbay ambrosia beetle is not known to be an important pest in its native range in Southeast Asia, but was known to be associated with members of the Lauraceae (laurel) family (Rabaglia, 2003). However, the unique association between insect, pathogen and host in which *X. glabratus* conveys the *R. lauricola* fungus into highly susceptible redbay trees has proven to be exceptionally fatal. The fungus spreads through the vascular system, blocking water transport, and causes redbay trees to wilt and die within months after initial infection. The wood of dying and recently killed redbay trees

serves as host material for *X. glabratus*, as well as other ambrosia beetles, which multiply rapidly, resulting in large numbers of beetles capable of spreading to new locations. Currently, *X. glabratus* is the only confirmed vector of *R. lauricola*, which causes vascular wilt disease in redbay and other Lauraceae species (Fraedrich 2008).

This new disease may eventually become much more widely distributed if it continues to spread in sassafras, which is found in much of the eastern half of the U. S. There are many additional genera and species in the laurel family, concentrated mainly in the tropical and subtropical areas in Central and South America, which may also be susceptible to LW disease.

Thus, it is important to document the advance of this disease both in geographic distribution and species affected. The spread of the laurel wilt disease has been tracked on the county-level as encountered by foresters and landowners since 2004 (Fig. 1). New counties were added to the map in GA when the presence of the pathogen in samples was confirmed by laboratory isolation. Based on this county-level data, it has been estimated that the spread of the disease has been about 20 miles per year over a four-year period in South Carolina (Boone 2008) and in all three states (SC, GA, FL) combined, the rate of spread has been estimated to be about 34 miles per year (Koch and Smith 2008). This pattern of expansion includes natural beetle dispersal as well as possible human-assisted spread. A single female beetle emerging from infested material can potentially start a new infection center. Female beetles carry the fungus in special pouches located at the base of each mandible and introduce the fungus when they chew through the bark into the wood in healthy trees. Human activities that move wood from beetle infested trees can certainly spread the disease over long distances to new locations.

To track the geographic distribution and rate of spread of the disease in a more comprehensive and systematic fashion, surveys have been conducted in Georgia and South Carolina in 2006/2007 (2006 survey) and 2007/2008 (2007 survey) supported by the USDA Forest Service, Forest Health Protection and the corresponding state forestry agencies in Georgia and South Carolina. The objectives of the surveys conducted in Georgia summarized in this report include:

- 1) Systematically document the distribution of LW disease on a grid pattern over the area known to be infected and beyond the apparent advancing front,
- 2) Determine the severity of infection within the range of distribution of the disease,
- 3) Document the rate and direction of spread and elucidate possible causes of varying rates of spread in across Georgia,
- 4) Investigate the symptoms and incidence of LW disease in sassafras and other species in the laurel family in Georgia, and
- 5) Lay the foundation for future monitoring projects.

Methods

Some plant taxonomists recognize three closely related species of *Persea*, including: *P. palustris* (swampbay), *P. borbonia* (redbay), and *P. humilis* (silkbay). Silkbay only occurs in Florida, but the ranges of swampbay and redbay overlap in Georgia. Swampbay and redbay are difficult to tell apart and are not universally recognized as separate species. Thus, for purposes of this survey and report, swampbay and redbay are considered to be one species, referred to as redbay.

**Distribution of Counties with Laurel Wilt Disease* Symptoms,
by Year of Initial Detection**

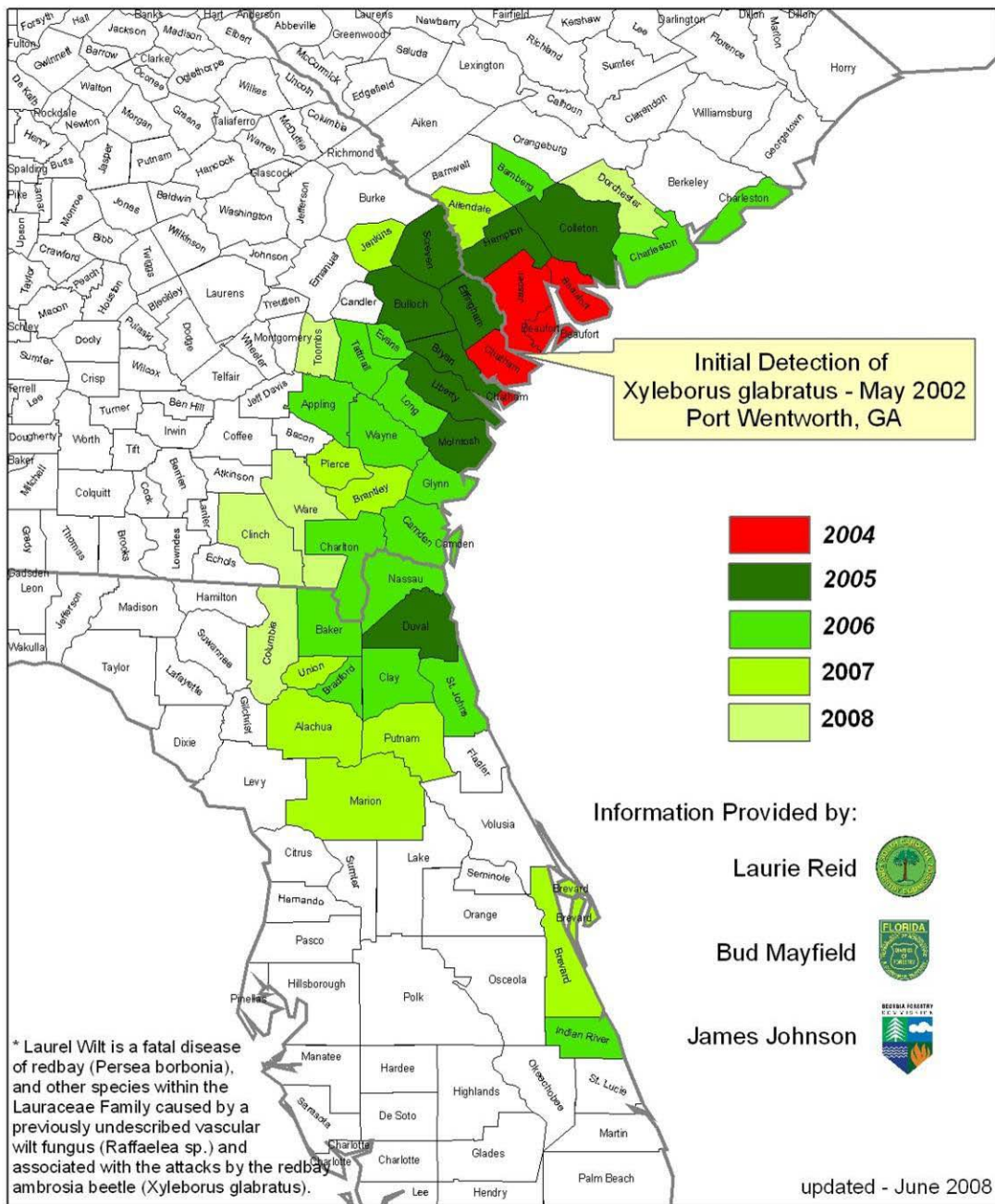


Figure 1. Counties in Florida, Georgia, and South Carolina confirmed to have laurel wilt disease by year of initial detection as of June 2008.

Systematic Redbay Mortality Survey

A systematic sampling procedure was used to delineate the incidence and intensity of laurel wilt disease in Georgia based on visual symptoms of disease on redbay trees. Redbay with wilted and/or dead foliage was used as the primary means for determining the range of LW disease. A 5 x 5 mile grid of potential plot locations was generated on the Georgia Forestry Commission (GFC) GIS system covering a broad area encompassing the counties known to have laurel wilt disease from prior GFC confirmation and the 2006 Georgia survey (Beck 2007), plus a band of additional counties to the north and west of the known disease distribution in southeast Georgia. The coordinates of the 2006 GA survey plots also were layered into the GIS system. A map with the grid points and 2006 survey plot locations was generated with ArcMap and printed out to serve as a guide for selecting survey plots.

Most of the 2006 survey plots were selected for reassessment and additional plots were added from the grid to provide a relatively uniform network of plots, approximately 10 miles apart. Additional plot locations were selected from the 5-mile grid as the survey progressed to better delineate the distribution of LW, especially in areas of sparse incidence along the advancing edge of the disease. A band about 15 to 20 miles wide, generally east of I-95, along the coast (including the barrier islands) was excluded from the present survey, since this area was considered to be generally infected. The Fort Stewart (Department of Defense) property in Bryan and Liberty counties and the Okefenokee National Wildlife Refuge in Charlton and Ware counties were not surveyed due to lack of access, with the notable exception of the Stephen Foster State Park Road in the Okefenokee Swamp.

Coordinates of selected plots were transferred to an Excel spreadsheet, which was used to further refine plot locations and plan survey routes. The selected plot locations were plotted on Google Earth using latitude and longitude coordinates, and if necessary, the plots were moved to a site with a high likelihood of public road access and the presence of redbay within a 2 mile radius of the original grid plot position. This became increasingly essential as the survey moved away from the coast to where farmland is more prevalent and redbay grows primarily at the edges of streams and river bottoms. The 2006 plot locations and the revised new plot locations were plotted on Delorme Street Map USA, and the most efficient daily travel routes were then designed prior to departure to the field each day. A Delorme Earthmate GPS receiver attached to a computer mounted in the survey vehicle was used to follow the route and locate plots in the field.

Field procedures. The actual 2007 plots were located where redbay would be included in the plot as near as possible to 2006 plots and the predetermined new plot positions. Sample plots consisted of one-tenth acre strips ca. 330' x 13.2' located ideally about 132' from the road edge and perpendicular to the road. A string line hip chain was used to measure the length of the plot and a plot center stick (Fig. 3) was used at arms length to estimate the plot width. In many areas, redbay distribution was not continuous or uniform and thus the plot direction was adjusted to incorporate as many representative redbay as possible. Some plots meandered to follow the redbay distribution and a few plots were doubled in width and cut to half the length if the plot ran into water, lack of redbay, or unsuitable land use (i.e. farmland). If redbay could not be located within about a 2 miles radius of the predetermined grid plot location, the plot was recorded with GPS coordinates as "no redbay."

Each plot was initiated at a redbay tree, designated as the plot origin. A TDS Recon portable data recorder equipped with GPS was used to record all plot data, including: sample number and date, GPS coordinates at the plot origin, direction of travel compass bearing, number of redbay killed by LW, number of live (healthy) redbay, and number of dead redbay killed by other causes. Only redbay trees greater than 1" diameter at breast height (DBH) were tallied. Initially, the number of "healthy" and "flagged" (dead branchlets often infested with another exotic ambrosia beetle, *Xyleborus compactus*) redbay trees were recorded separately, but due to the subjective nature of these categories and uncertain utility of this information, the "flagged" designation was discontinued and merged with healthy in a "live" redbay category. Additional data recorded for each plot included: LW severity (0 = none, 1-33% = light, 34-66% = moderate, and >66% = severe), number of redbay sprouts and seedlings (<1" DBH) in a one-fiftieth acre circular plot at the plot origin, presence or absence of redbay stump sprouts in the plot, and numbers of live and dead sassafras or other laurel species present in the plots. All data were also recorded on field data sheets and in some cases, additional notes were recorded about redbay abundance and LW disease in the area, plot characteristics, other tree health problems and causes of mortality, and suitability of the plot for future monitoring.

Redbay trees killed by laurel wilt are generally quickly and thoroughly colonized throughout the stem and branches by several species of ambrosia beetles, including *Xyleborus glabratus*, *Xylosandrus crassiusculus*, among others. The boles are also invaded by wood rotting fungi, which hasten the decomposition process. Thus, trees killed by laurel wilt tend to "break up and fall apart" within a couple years after being killed by the fungus. During the early phases of this decomposition process, however, wood moisture content remains high for an extended time, permitting the development of large numbers of ambrosia beetles. In plots evaluated in areas where the disease had already heavily impacted the redbay population, redbay stumps and broken stems were assumed killed by the disease and tallied as "LW dead" (Fig. 3).

In plots where the cause of death of redbay was uncertain, patches of bark were removed and/or small stems cut to determine if the black staining of xylem tissue characteristic of LW was present (Fig. 2). If not, it was assumed that the mortality resulted from other causes. Sometimes the cause was apparent, for example in the case of fire damage. When dead redbay trees were encountered in counties not previously confirmed to have LW, sections of stems and/or wood chips were collected and sent to Dr. Stephen Fraedrich (USDA, Forest Service, Athens, GA) for laboratory culture to confirm the presence of the fungus before being documented as positive for LW.



Figure 2. Redbay tree with bark removed to expose the black staining of the wood characteristic of LW infection.



Figure 3. Stump and sprouts of a redbay tree killed by laurel wilt (left of orange plot center stake). Although all the larger redbays in the area had been killed by laurel wilt, small redbay trees (orange flagging in the background), and most seedlings and sprouts are still alive.

Survey timing. Redbay trees retain their dark-green leaves in the winter and trees killed by LW retain the red to chocolate brown dead leaves for many months after dying, both of which are easier to see during the winter when the “woods are more open” because deciduous vines, bushes, and trees are without leaves. It is much more difficult to see live or dead redbay trees once deciduous plants leaf out and redbay trees have new, light-green foliage in the spring. Thus, nearly all survey plots were installed and assessed from November 27, 2007 to March 31, 2008. A few “special” plots detected by private land owners and GFC foresters off the main survey grid were assessed for LW infections at other times of the year. Since this survey generally documented dead and dying trees sampled in the 2007/2008 winter, the survey was essentially assessing infections through the end of 2007. Thus, this survey will be referred to as the “2007 survey” as compared to the grid survey conducted the previous year, which will be referred to in this report as the “2006 survey.”

Data entered on the Recon data recorder were transferred periodically during the sampling period into the GFC GIS/database system. These data were converted to Excel spreadsheet format for purposes of editing and subsequent analysis and presentation of survey results. Maps displaying the locations and relative LW infection levels in plots from the 2006 and 2007 surveys were developed using ArcMap on the GFC GIS system.

Laurel Wilt in Sassafras, Pondberry, and Pondspice

One objective for this project was to characterize and investigate the incidence of laurel wilt in sassafras, pondspice, and pondberry. Since sassafras and redbay have different site preferences, they seldom overlap on a small plot of land or even on a broader geographic scale as illustrated on the distribution maps for redbay and sassafras presented in Koch and Smith (2008). In addition, sassafras is a deciduous tree and blends in with other deciduous trees in the winter when most of the systematic LW survey was conducted in 2007-2008. Furthermore, the health of sassafras trees is difficult to ascertain with leaves off in the winter. Thus, no sassafras was detected on any of the redbay grid survey plots. The authors became more adept at recognizing sassafras when they flowered and leafed out in the spring and a number of sassafras clumps, mostly along roadsides and fence rows, were identified and surveyed for disease incidence in the spring of 2008. These sassafras plots generally were located in association with travel for other purposes or special targeted sassafras survey trips and thus they are clustered in a few areas and do not represent the actual distribution of sassafras across the entire grid area sampled in 2007.

Pondspice and pondberry are scarce and disperse, often occurring together on poorly drained, swampy depressions associated with small sand dunes. Special field visits to two sites with these two species were conducted during the 2007/2008 survey period. One was near Clyo in Effingham County and the other in Wheeler County near McRae, Georgia. Both site visits were coordinated by Tom Patrick with the Georgia Department of Natural Resources.

Results and Discussion

A total of 237 plots were recorded in the 2007 Georgia laurel wilt survey. Of this total, 188 had at least one redbay and 19 were in areas where “no redbay” could be found within a reasonable distance (ca. 2 miles) of the pre-established plot center. Another 30 plots were identified as sassafras plots with no redbay present. Only one redbay plot was assessed for each of Wheeler, Burke, and Chatham counties, which were disregarded and not included in the summary data due to the lack of multiple plots. Among the plots with redbay, 102 plots had no redbays with laurel wilt symptoms (none), 34 were lightly infected with laurel wilt disease (1-33% of redbay trees infected), 26 were moderate (34-66 % infected), and 26 were severe (66-100% infected).

Laurel Wilt Infection by County in Georgia

Data were summarized for each of 24 counties included in the 2007 grid survey by computing the mean among plots sampled in each county for percent laurel wilt dead, percent live, percent other dead, percent of plots with stump and/or basal stem sprouts, and the mean number of seedlings and root sprouts per acre (Table 1). Counties closest to Savannah that have had LW disease the longest, generally had the highest percent of the redbay trees killed by the disease. To illustrate, counties are listed in four percent infection classes as follows:

- 1) Greater than 45 percent dead redbay trees - Bryan, Bulloch, Effingham, and Liberty,
- 2) 30-40 percent dead - Camden, Evans, McIntosh, and Screven,
- 3) 10-30% dead redbay - Charlton, Glynn, Long, Tattnall, and Wayne, and
- 4) Less than 10 percent – Appling, Brantley, Clinch, Jenkins, Pierce and Toombs.

Bacon, Candler, Emanuel, and Jeff Davis counties had no laurel wilt disease detected.

Table 1. Numbers of plots and plot means for percent of redbay trees dead from laurel wilt, percent live, percent dead from other causes, percent of plots with stump/ stem sprouts and mean number of redbay regeneration (root sprouts and seedlings) by county in the 2007 Georgia laurel wilt survey.

Redbay Plots		Plot Means by County				
County	# Plots	% LW Dead	% Live	% Other Dead	% with Sprouts	# Regen per Ac
Appling	16	8.1	91.0	0.9	18.8	884
Bacon	4	0.0	100.0	0.0	0.0	38
Brantley	10	1.3	97.0	1.7	0.0	355
Bryan	4	55.0	44.4	0.6	50.0	313
Bulloch	13	48.6	48.4	3.1	69.2	554
Camden	10	35.1	64.9	0.0	30.0	675
Candler	3	0.0	100.0	0.0	0.0	33
Charlton	10	21.8	78.2	0.0	20.0	145
Clinch	5	2.9	97.1	0.0	20.0	400
Effingham	8	71.0	28.4	0.6	75.0	894
Emanuel	6	0.0	97.2	2.8	16.7	258
Evans	8	35.9	63.2	0.8	50.0	813
Glynn	3	12.8	87.2	0.0	33.3	150
Jeff Davis	5	0.0	100.0	0.0	0.0	140
Jenkins	7	1.3	90.6	8.1	0.0	264
Liberty	5	50.6	49.4	0.0	80.0	630
Long	8	14.0	84.5	1.6	62.5	463
McIntosh	5	41.2	58.8	0.0	40.0	550
Pierce	7	5.9	92.4	1.7	14.3	357
Screven	11	36.2	59.8	3.9	36.4	359
Tattnall	11	15.6	83.8	0.6	0.0	132
Toombs	6	0.6	99.4	0.0	0.0	108
Ware	7	2.6	95.1	2.3	28.6	179
Wayne	16	19.0	75.3	5.7	37.5	538
Total	188	21.2	77.0	1.8	29.8	440

Relatively few redbay trees observed in this survey had clearly died from other causes with an average over all the plots of 1.8 percent. Stump sprouts were often numerous around dying and dead redbay trees, although many eventually die (Fig. 3). The proportions of plots with sprouts and amount of regeneration (root sprouts and seedlings combined) appeared to be significantly correlated with LW mortality rate (Table 2). There were fewer plots with stump sprouts and less regeneration in plots without LW and increasing amounts of both with higher levels of damage (Table 2). However, this relationship could also be confounded by the distribution of redbay trees and LW damage levels. Many of the plots without damage were located near the limit of redbay distribution where redbay trees and regeneration are scarce.

Table 2. Percent of redbay plots with stump sprouts and mean amount of regeneration/Ac by percent redbay mortality class among all 2007 LW survey plots.

<u>% LW mortality</u>	<u>% of plots with stump sprouts</u>	<u>Mean number root sprouts & seedlings/Ac</u>
None	8	325
1-33%	20	474
33-66%	78	622
> 66%	87	733

It has been documented that large redbay trees become infected and die more rapidly than smaller diameter trees (Fraedrich et al. 2008). This was also observed throughout this survey, with very few large redbay trees remaining alive where the disease had been present for a number of years. However, there were many relatively small redbay trees, mostly in the 1 to 4 inch DHB range, still alive in plots, even in very heavily infected areas. Also, disease severity was not uniform within the general area of infection. There were a few plots near Savannah in Chatham, Bryan, and Effingham counties that had no disease or only light infection rates. At least for now, redbay has not been eliminated from the ecosystem as has been suggested might occur. The question remains unanswered as to what will happen to these remaining healthy redbay trees over time.

Comparison of 2006 and 2007 Laurel Wilt Infection Levels by County

Infection levels in plots sampled in the 2006 and 2007 were compared to demonstrate the increase in rate of infection over a one year time frame. Due to land use alterations, inaccessibility, and inconsistencies in data collection, only a portion of the plots could be used for this comparison. A total of 47 plots were compared in 15 counties. The mean percent infection was computed for the plots in each county for comparison (Figure 4). These means derived from selected plots differ somewhat from the county averages among all plots reported for the 2007 survey, but this comparison serves to illustrate that the infection rate increased rapidly in these counties over a period of one year, more than doubling from an average of 21 percent infection in 2006 to 46 percent in 2007.

Geographical Distribution of Laurel Wilt in Georgia

The coordinates and severity code for each plot in the survey were loaded on the GFC GIS system and a map was produced with color coded dots indicating the plot locations and laurel wilt infection severity (black = none, green = light, yellow = moderate, and red = severe) in the 24 counties sampled in the 2007 grid survey (Figure 5). The locations of sassafras clumps encountered during the survey and other travel opportunities were plotted on the map as stars using the same relative severity color codes as for redbay plots.

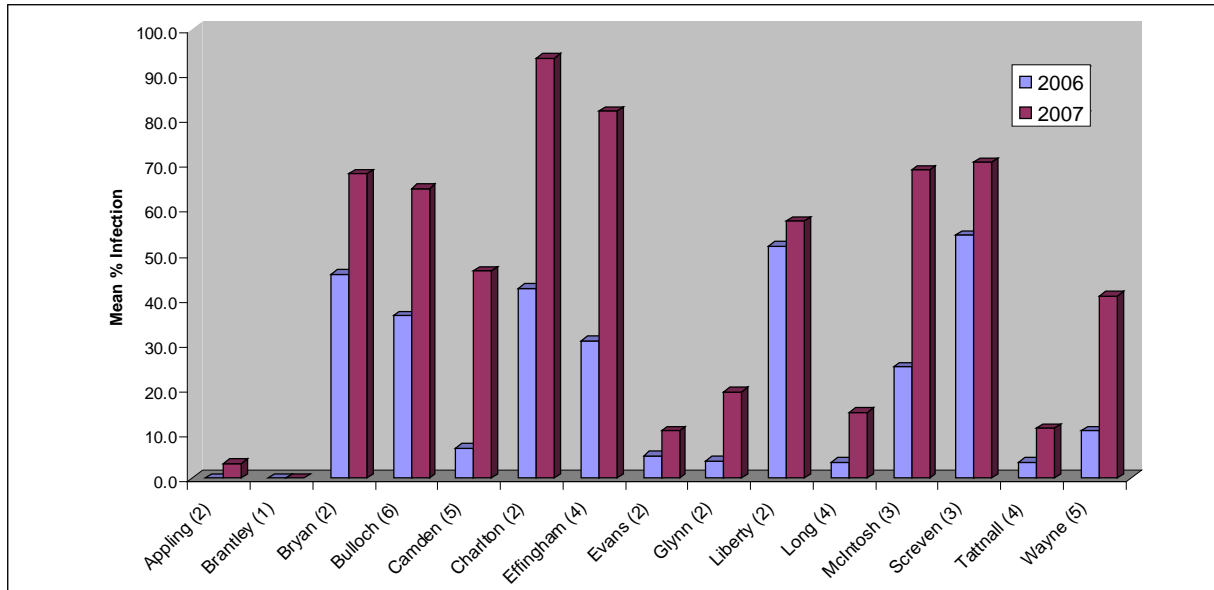


Figure 4. Comparison of mean percent LW infection by county for plots evaluated both in the 2006 and 2007. Numbers in parentheses indicate the number of plots included in the average for each county.

At first glance, little sense could be made of the arrangement of color coded dots on the survey map. However, by drawing a line at the interface behind which (to the east toward the original introduction in the Savannah area) all or nearly all the plots were infected with LW to some degree and ahead of which there is a series of uninfected plots, the pattern of distribution became much more evident (Figure 5). It also gave rise to the appearance of “outliers” ahead of the “general area of infection.” These outlying infection centers (indicated by orange lines in Figure 5) are surrounded by uninfected plots or are long tongues extending beyond the general area of infection, which might indicate that the disease spread was assisted by human activities (see Anthropomorphic (Man-assisted) Spread section below).

The wedge including most of Brantley County, southern Glynn, and northern Camden counties where laurel wilt was not found suggests that there was an introduction of the redbay ambrosia beetle and laurel wilt disease in Florida separate from the original introduction in the Savannah area. This infection front appears to be moving north and west in extreme southern Georgia. The history of the disease spread through the barrier islands in Georgia discussed below also supports this hypothesis.

In order to cover a large geographic area in a short period of time, this survey was restricted to developed areas with roads and public access. It was apparent throughout the grid survey that redbay has been significantly impacted by land management practices such as farming, timber harvest, pine plantation management, burning, herbicide usage, and urban development. Some of the most abundant and largest redbay trees are undoubtedly located in inaccessible, undeveloped areas that have not been harvested recently or converted to pine and were not surveyed. Redbay trees are often abundant in managed pine plantations, but generally relatively small, seldom exceeding six inches in diameter. Many of the redbay survey plots were located in pine plantations in wind rows or under the canopy of the pines where redbay seeded in or sprouted back after plantation establishment.

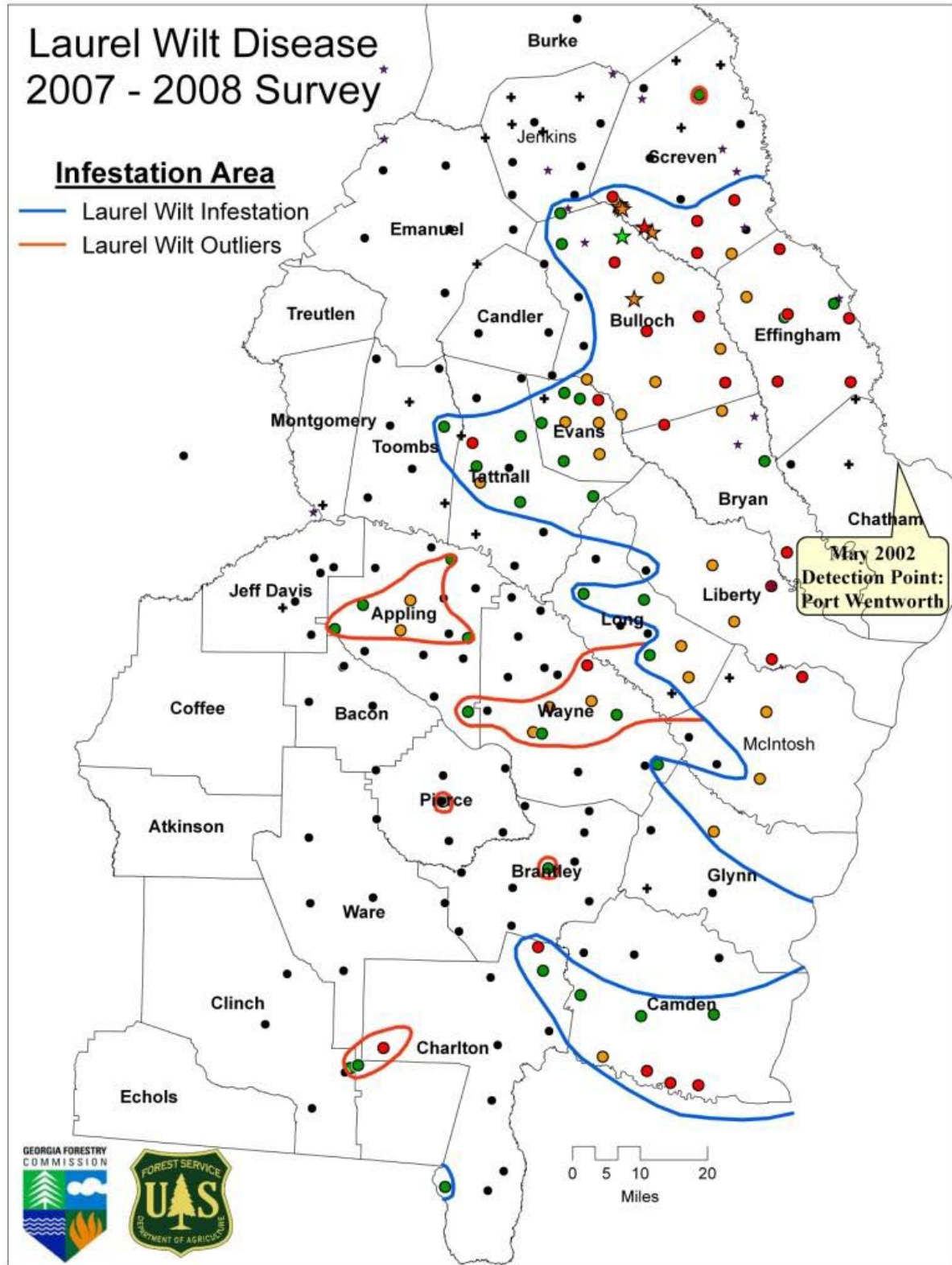


Figure 5. 2007 Georgia laurel wilt survey plot locations indicating four levels of infection (black = none, green = light, orange = moderate and red = severe). Plus signs (“+”) indicate no redbay found. Stars indicate the locations of groups of sassafras trees. The blue lines delineate the apparent advancing front toward the west (left) or general area of infection of the disease and the orange lines delineate apparent outlying infection centers.

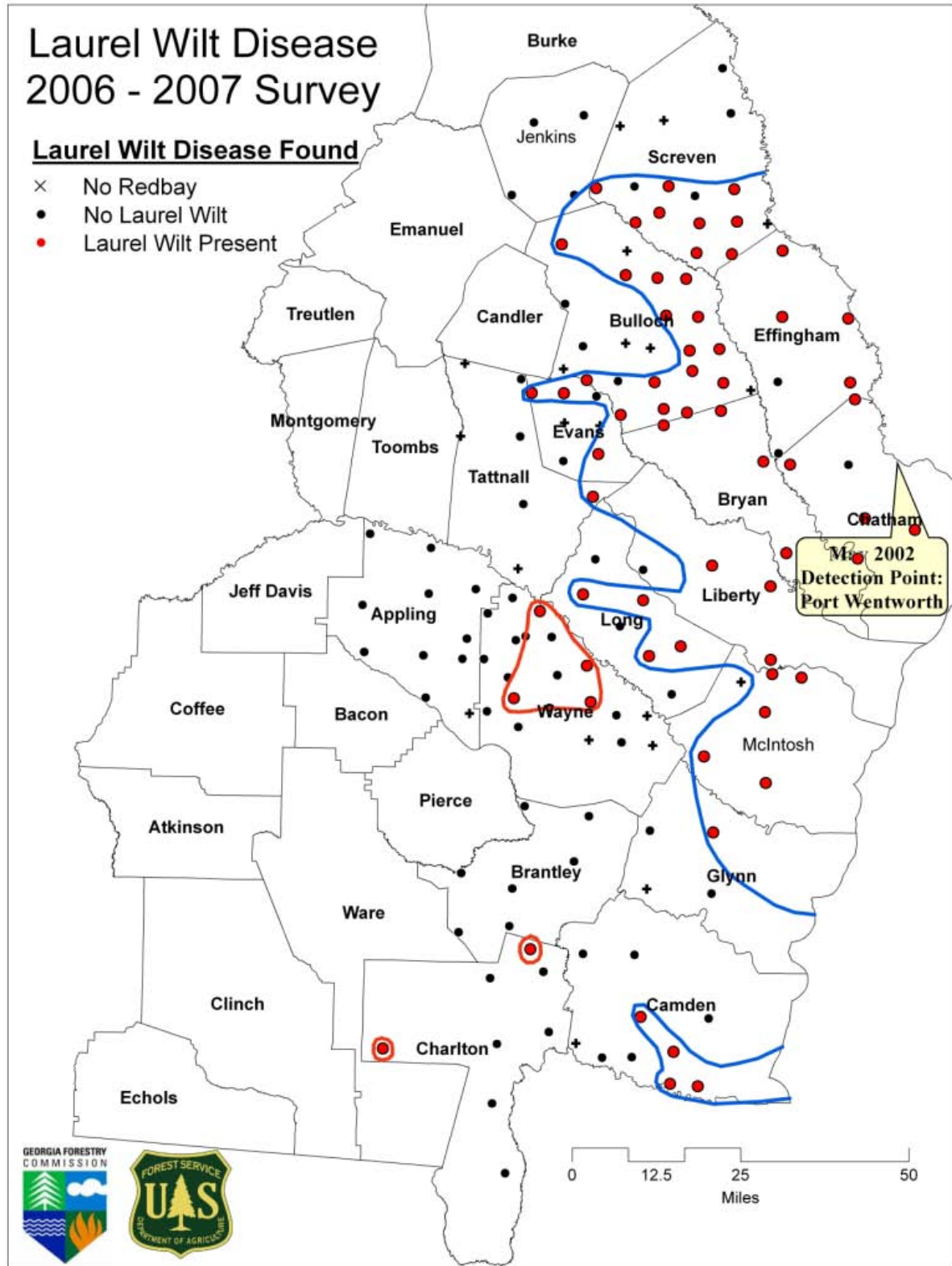


Figure 6. 2006 Georgia laurel wilt survey plot locations indicating presence (red dots), absence (black dots) and no red bay plots (plus sign “+”). The blue line delineates the apparent advancing front of the disease with the “general area of infection” to the right. The red lines delineate outlying infection centers.

On several occasions, laurel wilt was not found at the predetermined sample points, but diseased trees were observed en route to another plot located within 5 to 10 miles. In such instances, an additional plot was often established to document the presence of LW, especially in areas where LW was scarce. Also, GFC Foresters found a number of outlying redbay infections while carrying out their normal duties or through landowners who contacted them about dying redbay trees. Several plots were established at these locations to supplement the grid survey.

In one instance, a supplemental plot was established in Pierce County after a property owner notified a GFC forester of dying redbay trees on his property across the street just 300 yards away from a grid survey plot that was disease free. This mortality was confirmed to be caused by LW and represents the only location found to have LW in the entire county. Another example occurred along the road to Stephen Foster State Park in the Okefenokee National Wildlife Refuge, where GFC foresters confirmed the presence of LW in two locations just miles apart in Ware and Clinch counties. These also are the only confirmed LW infections in either of these counties and resulted in filling in these two counties on the laurel wilt county distribution/spread map (Fig. 1).

Spread of Laurel Wilt Disease in Georgia

Spread of LW Disease from 2006 to 2007 in Georgia. To evaluate the spread of LW during the one year period between the 2006 and 2007 surveys, the points from the 2006 survey were plotted on a map similar to that produced for the 2007 survey described above (Fig. 5). The severity codes for the 2006 survey were converted to no laurel wilt (black dots) and laurel wilt present (red dots) due to differences in classification between the two surveys, and the advancing front and outlying infection centers were delineated with blue and red lines, respectively (Fig. 6). This provides an effective visual comparison of the disease distribution and spread. There were several “outlying” LW infections in 2006 as was found in the 2007 survey.

The spread of the disease north and west in the northernmost counties surveyed in Georgia was negligible, probably due in large part to the sparse distribution of redbay, as indicated by the number of “no redbay” plots in the area. The greatest spread was westward into Appling and Tattnall counties. The area infected in Appling County was the farthest extension of the disease to the west, but this area is not contiguous with the general area of infection to the east and may be an outlier spread by human activities. Other notable areas of disease spread were a finger of expansion through Wayne County into Appling County and an area filled in between infections in Camden and Brantley counties. There was little advance of the disease toward the south in Glynn County, which is puzzling since redbay is fairly abundant in the plots monitored. However, there are large areas of urban development, marshland and tidal waterways in parts of Glynn County.

The infected area in western Appling County stands out with six positive plots detected in the 2007 survey, while no disease was detected in this area by the 2006 survey (Fig. 6). However, LW disease was confirmed by Chip Bates (GFC forester) to be present in 2006 from “off-grid” locations in western Appling County (Fig. 1).

History of LW Spread on Barrier Islands. The Georgia Forestry Commission first received reports of redbay mortality near Savannah, Georgia in 2004. However, John Crawford (University of Georgia Marine Extension Service) later indicated that he first recorded redbay trees dying on Ossabaw Island in March 2003. He also noted similar mortality on Skidaway Island approximately one year later in 2004. The Director of the Georgia Forestry Commission and some of his staff confirmed the presence of LW disease on St. Catherines Island during a visit in January 2004. Thus, it can be deduced that it was already present in 2003. In the fall 2005, GFC foresters (Bates, Fell, and Johnson) and Stephen Fraedrich (US Forest Service) went to Sapelo Island to investigate reports of an area infected with LW on the northern end of the Island that encompassed less than 10 acres at that time. By the summer 2006, redbay mortality was observed over the entire northern half of the island with an estimate of at least 70% mortality among the larger, mature redbays.



Figure 7. Map of barrier islands in Georgia with years of first report of laurel wilt disease.

National Park Service personnel reported Cumberland Island had redbay mortality in 2006 and this is thought to be the northern movement of the insect and disease from a separate Florida disease front. In September 2006, Chip Bates (GFC) discovered isolated pockets of redbay mortality on Jekyll Island. The last island to be impacted is St. Simons where LW in redbay was not observed until 2008. The map above (Fig. 7) shows the year of first detection of laurel wilt disease on some of the Georgia barrier islands. The spread through the islands can be assumed to be natural dispersal of the redbay ambrosia beetle, both southward from Savannah and northward from Florida. Several of these islands do not have roadways and are only accessed by ferry, including Cumberland, Sapelo, St. Catherines, and Ossabaw islands. However, boaters might have cut and transported beetle infested firewood through the Atlantic Intracoastal Waterway or off shore to new and possibly distant locations.

Calculated Rate of Spread. By measuring the distances between the leading edges of the 2006 and 2007 surveys, distance is about 15 miles or less in most locations. Perhaps of greater significance are infection centers in Appling county about 30 miles in advance of the 2006 distribution and the other outliers in Pierce and Brantley counties.

An estimate of spread since the initiation of this disease episode can be derived by dividing the total distance from Port Wentworth, Georgia to the farthest points of expansion in 2007, divided by the number of years the disease has been advancing. Assuming that redbay trees started dying from LW disease in the Savannah area in 2003 and that a separate introduction occurred in north Florida from which the disease is advancing northward in south Georgia, the farthest spread to the north, west and south in Georgia is about 55 to 70 miles through the four

years from 2004 through 2007. That computes to an annual spread rate of 15 to 17.5 miles per year, which is slightly less than 20 miles/year estimated by Boone (2008) and about half the distance derived by Koch and Smith (2008) based on a 2007 LW county spread map for Georgia, Florida, and South Carolina.

Another possibility that should be considered in the calculation of the rate of spread is that the date of initial mortality may have been earlier than assumed and the number of years of spread may be underestimated. It is worth noting that St. Catherines Island already had infected redbays in 2003. The northern tip of this island is about 30 miles from the Port of Savannah. At a rate of spread of 15 miles/year, it would have taken 2 years to spread from Savannah to St. Catherines Island. Thus, one should subtract at least two more years from the year that first infections occurred in the Savannah area, which would set the initiation of spread at the year 2001. Thus, the rate of spread per year would become 9 to 12 miles/year.

Factors Influencing Natural Disease Spread

Griffith et al. (2001) developed a map for Georgia delineating ecoregions and subregions with similar geology, physiography, vegetation, climate, soils, land use, fauna, and hydrology (Fig. 8). Georgia's Sea Islands/Coastal Marsh subregion has the most extensive maritime forest within the southern Atlantic zone. This maritime forest with live oak overstory and diverse understory that includes redbay as a primary component has provided abundant host material for redbay ambrosia beetles, resulting in large populations that have already spread the disease throughout most of the barrier islands. The potential for natural spread of the disease is far greater in areas with high and continuous concentrations of large diameter redbays compared the distribution fringes where redbay trees are generally small and widely scattered. Laurel wilt has steadily spread about 75 miles westward through the northern half of the Southern Coastal Plain and is poised to continue spreading south and west in the southern half of this ecoregion. The rate of spread apparently slowed as the disease reached the Southeastern Plain region to the north and may be limited in this region unless it transitions into sassafras and continues advancing to the north (see the Laurel Wilt in Sassafras section below).

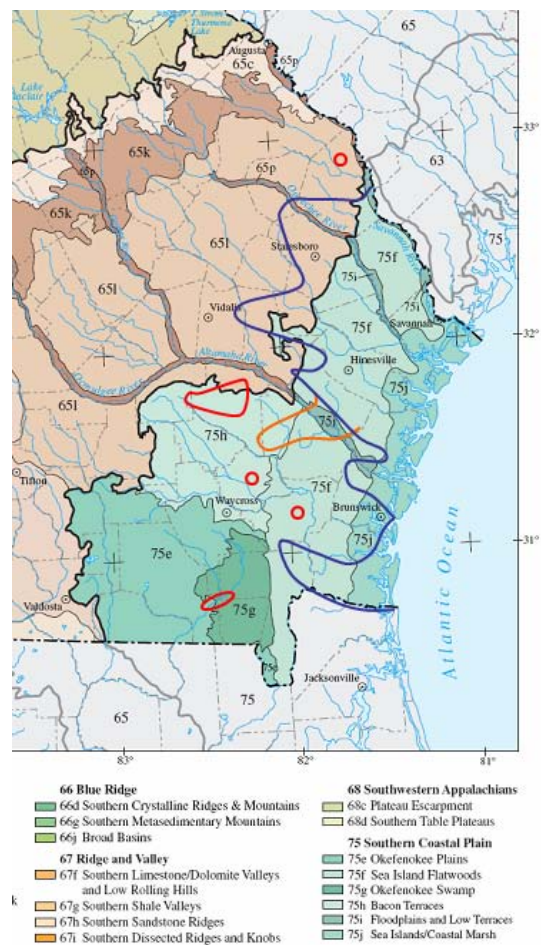


Figure 8. Ecoregions of Georgia (Griffith et al. 2001) with the general area of LW infection delineated from the coast to the blue line and outlying infection areas outlined in red and orange.

Addressing the difficult task of predicting future spread of LW, Coder (2006) prepared a laurel wilt risk assessment map for Georgia (Fig. 9), while Koch and Smith (2008) developed a model and map predicting the rate of spread and eventual geographical distribution of laurel wilt. These estimates are based on a number of factors that will likely influence the direction, rate, and extent of laurel wilt disease spread including: climate, presence of susceptible hosts, and density of hosts. Interestingly, the actual advance of LW disease has, as predicted, spread through the highest risk area proposed by Coder (2008) and is now at the outer edge of the second highest risk area to the north and expanding into that same risk level 2 in south Georgia.

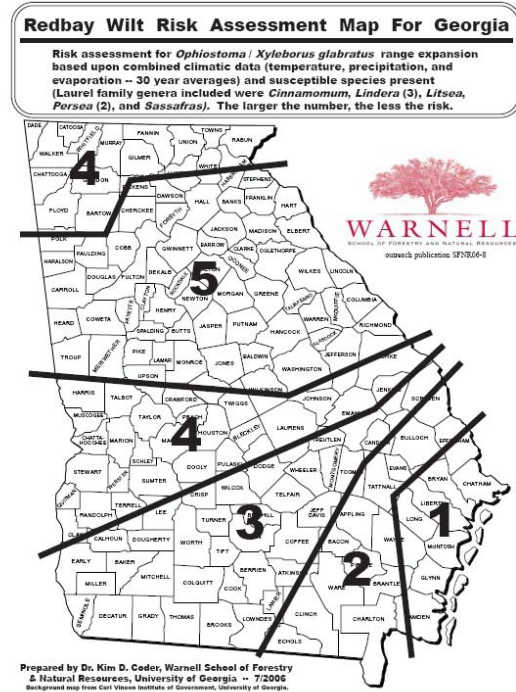


Figure 9. Redbay wilt Risk Assessment map for Georgia (Coder 2006).

Koch and Smith (2008) developed distribution maps for redbay and sassafras based on USDA Forest Service, Forest Inventory Analysis data (Fig. 10) for use in their prediction model. Several variables possibly influencing the spread of LW disease that are not included in these models include: 1) volume of host material (density of hosts is based on numbers of stems per unit area and does not account for tree size, thus host volume may be a more reliable variable), 2) relative host susceptibility of redbay and sassafras (sassafras may not be as attractive or produce as many redbay ambrosia beetles as redbay), 3) natural and artificial barriers (large swamps, flooded bottomland, lakes, tidal zones with extensive marsh land, farmland, and densely populated urban areas may block or slow the spread), and 4) human-assisted (anthropomorphic) spread (a critical but less predictable variable). The anthropomorphic component is incorporated in the Koch and Smith model since they based the rate of spread on county spread maps developed for Florida, Georgia, and South Carolina from 2004 through 2007, which include all means of dispersal.

Anthropomorphic (Man-assisted) Spread

Although it is not possible to definitively distinguish natural from anthropomorphic spread, there are a number of isolated infection centers or long fingers extending beyond the general area of infection that are highly suggestive of spread assisted by man's activities. A number of "outliers" are located near population centers where manufacturing facilities are located that might receive unprocessed wood materials harboring *X. glabratus*, transported over long distances, or where the probability that individuals have transported small quantities of infested wood is greatly increased. Examples include outlying infections near Baxley in Appling County, Jesup in Wayne County, Blackshear in Pierce County, and Nahunta in Brantley County (Fig. 5).

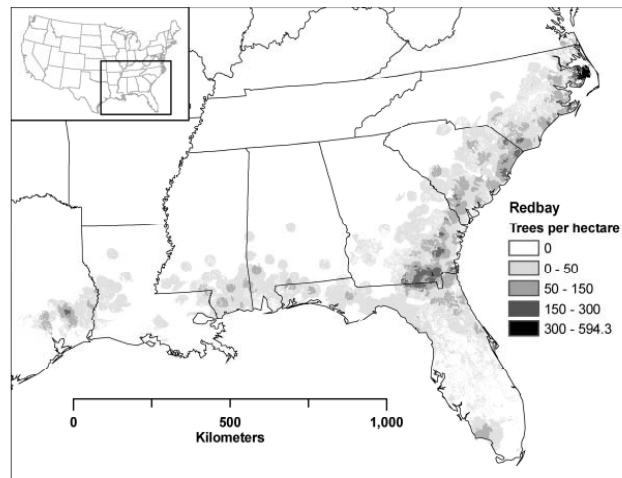


Fig. 2. Map of redbay density in trees per hectare.

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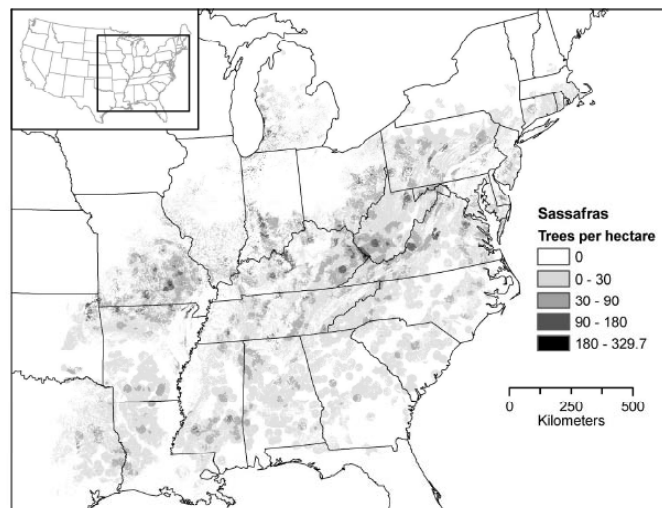


Fig. 3. Map of sassafras density in trees per hectare.

Figure 10. Distribution maps for redbay and sassafras based on USDA Forest Service, Forest Inventory Analysis data, copied from Koch and Smith (2008).

Two of these are described in detail below. A nearly certain case of man-assisted spread involving an infection center that developed in Stephen Foster State Park also is detailed below.

Railroad in Jesup, Georgia. The Georgia Forestry Commission received notice of redbay mortality in Wayne County, Georgia in early spring 2006 near the state prison (south of Jesup). The infested site was surveyed (Mark McClellan, GFC Forester) and found to be centered on a rail line, and surveys of the immediate surrounding area revealed no additional dying redbay trees. There is a large pulp mill located to the north of this site (about 3 miles) and rail cars are stored for periods at the infestation site. The pulp mill receives chips via rail and redbay ambrosia beetles associated with wood chips may have served as the source of this introduction.

However, it is also possible that the spread of LW into this area was a natural extension of the leading edge of the disease.

Mulch plant near Nahunta, Georgia. The 2007 survey detected LW disease in one isolated plot in Brantley County, surrounded in all directions by plots without the disease. This plot (positively confirmed to have *R. lauricola* - S. Fraedrich, personal communication) was located immediately adjacent to a large mulch plant, which suggests that raw material used by this facility might have carried *X. glabratus*, which introduced the disease into the area.

Stephen C. Foster State Park. This park is located on a peninsula of land on the western side of the Okefeenokee National Wildlife Refuge. Park managers noticed redbay mortality in 2004, which was initially attributed to prescribe burning that took place in one section of the campground. In May 2006, Park officials attended the GOAL (Greater Okefeenokee Area Landowners) meeting where information on the redbay ambrosia beetle and associated laurel wilt disease was presented. They then took a closer look at the redbay mortality and realized it was also occurring in areas that had not been burned and contacted the Georgia Forestry Commission. Veteran GFC forester Mark McClellan made a site visit, recognized the symptoms of LW disease, and sent in wood samples to verify the presence of the *R. lauricola*.

Further investigation revealed that this outbreak was localized and no sites within 75 miles were known to be infected with the disease at that time. The nearest known occurrences were in Duvall County in Florida and the coastal areas of Glynn and Camden County in Georgia. For this to have been natural spread of the disease, it would have had to cross one of the largest freshwater wetlands in the U.S. (the Okefeenokee Swamp) where minimal redbay occurs.

Park managers indicated seeing the first redbay die within the actual campground area. Thus, our best theory as to how this LW disease center was initiated is that the insect and pathogen were likely introduced via infested firewood brought in by a camper. LW disease around Stephen Foster State Park is still localized with the farthest known diseased trees (as of May 2008) located about 7 miles from the initial point of infection. Furthermore, no other laurel wilt disease has been detected in extensive ground surveys in areas west and northwest of this disease center, thus giving further evidence that the introduction point was indeed the state park.

Laurel Wilt in Other Lauraceae Species

Laurel Wilt in Sassafras. Prior to the 2007 Georgia survey, laurel wilt disease was found in sassafras trees in Effingham, Evans, Bulloch, Liberty and McIntosh counties by Chip Bates (GFC) and confirmed through laboratory isolation of the *R. lauricola* fungus by Stephen Fraedrich. Sassafras is relatively inconspicuous and blends in well with many other mid-story and understory trees during much of the year and was only spotted at a couple locations during the main 2007 LW survey. Also, sassafras apparently is relatively rare (Fig. 10) in most of the area covered by the 2007 laurel wilt grid survey. However, a number of clumps of sassafras were detected in the spring of 2008 when the trees became more noticeable, usually growing on disturbed sites along fence rows, edges of cropland, and road sides. Sassafras trees stand out in early spring when striking pale yellow staminate and pistillate flowers emerge on separate (dioecious) trees at the ends of branchlets prior to leaf out (Fig. 11). Sassafras flowering occurs just prior to the loblolly pine pollen flight, which could be used for timing future surveys or locating monitoring plots. Another time of the year when sassafras would be easier to find is in

the fall when the leaf color changes from green to distinctive mixtures of bright salmon, red, and yellow (Fig. 11).



Figure 11. Sassafras albidum characteristics for field identification. Center and top center - early spring flowering before leafout (prior to loblolly pine pollen flight), top left - staminate flower cluster, top right - pistillate flower cluster, bottom left - crown in full fall color, and bottom right - fall leaf color.

Among the 30 sassafras locations documented in this survey, numbers of live and dead trees over one inch diameter were counted and recorded for 18 plots. Among these, eight were diagnosed with laurel wilt, with 25 to 67 percent of the sassafras stems dead or dying. These infected clumps were located within 15 miles of each other in northern Bulloch and southeastern Screven counties and all were within the LW general area infection in redbay.



Figure 12. Top photo taken 5/12/2008 - Clump of Sassafras albidum near Statesboro, GA showing initial symptoms of LW (darker green center-left reflects shadows in this photo). The bottom photo taken 7/25/2008 illustrates symptoms and advancing LW disease scattered throughout this clump of sassafras (Note: colors in the bottom photo have been electronically enhanced to convey actual color differences).

LW disease appears to run through these sassafras clumps rapidly with scattered trees wilting at varying rates. In one sassafras stand located near Statesboro, Georgia, trees all leafed out in the spring of 2008 without obvious symptoms of disease. On May 12, several trees were noted with wilting or fallen leaves and by July 25 trees throughout the clump were either dead or showing symptoms of disease (Fig. 12). In cursory inspections of diseased sassafras trees, few or no ambrosia beetle holes were found, raising the question as to how they became infected and suggesting that the disease may be moving systemically through the clump. Sassafras is known to grow in clones from root sprouts and further study of these and other sassafras stands is warranted.

These sassafras infection centers in northern Bulloch and Screven counties are of particular interest because they are located at the leading edge of the disease spread, in an area where redbay is relatively scarce, and where the disease would have to transition from redbay to sassafras if it is going to continue spreading far beyond its current distribution to the north and west. Hanula and others (2008) found that “freshly cut sassafras was not attractive to *X. glabratus*, suggesting that the spread of laurel wilt may slow once it reaches the edges of the range of redbay.” This hypothesis may be tested shortly.

Laurel Wilt in Pondberry and Pondspice. One site near Clio, Georgia was visited in June 2007 to assess the health status of pondberry (*Lindera melissifolia*) and pondspice (*Litsea aestivalis*) growing in close proximity (Fig. 14). There were several dead redbay trees killed by LW adjacent to pondberry and pondspice at the edge of the then dry swampy depression. The laurel wilt fungus, *Raffaelea lauricola*, was previously isolated from both pondberry and pondspice at this site, but *X. glabratus* was not found (Fraedrich 2008). A few wilting pondberry plants were found in June 2007, apparently attacked and killed by *X. compactus*. Several multi-stemmed pondspice plants were either dead or had dead branches. Some of the branches had bark peeling off reminiscent of freeze damage, which may have resulted from the unusual “Easter freeze” that occurred on April 4-6, 2007 (Fig. 13).



Figure 13. *Litsea aestivalis* with bark split open, possibly caused by freeze damage.

Another pondberry and pondspice site was visited by Tom Patrick (DNR), Dr. Richard Carter (Valdosta State University), James Johnson and Scott Cameron (GFC), Kimberly Spiegel (Georgia Southern University), among others on January 30, 2008 in Wheeler County near McRae, Georgia. This too was a swampy depression that was dry at the time. Since both pondberry and pondspice are deciduous, it was difficult to assess plant health at that time.

To track the progression of LW disease in pondberry and pondspice, plots need to be set up and monitored at periodic intervals. The two sites visited during this project might serve well for this purpose since redbay, pondberry, and pondspice are in close proximity at both sites, and one is located in an area already heavily impacted by LW disease, while the other is still 20 to 30 miles beyond the farthest known western extension of the disease. Timing of visits to assess plant health should be from March to October. These plants are both dioecious and flower before leaf out in the spring and fruits can be found in October.



Figure 14. Pondberry, *Lindera melissifolia* (foreground), and pondspice, *Litsea aestivalis* (background) in Effingham County, Georgia.

Laurel Wilt in Camphor Tree. One camphor tree (*Cinnamomum camphora*) with dieback symptoms located in McIntosh County in the midst of severe LW mortality of large redbay trees was discovered by Chip Bates (GFC) in June 2007. Symptoms were different from those on redbay in that only shoots and branches were dead while the remainder of the crown was alive, somewhat similar to fire blight in pear trees (Fig. 15). Dr. Stephen Fraedrich (USDA Forest Service) isolated *R. lauricola* from samples taken in June 2007 from this camphor tree. A repeat visit in April 2008 revealed that the tree had generally recovered from the dieback and showed little evidence of disease. However, the fungus was still present in the tree as *R. lauricola* was isolated from samples of small symptomatic branches taken in the vicinity of the previous year's dieback (Stephen Fraedrich, May 10, 2008).

Camphor trees are in the Lauraceae family and originate from Asia and have been widely planted in far southeastern U. S. The recovery of this tree after showing symptoms of disease suggests inherent resistance which may have evolved through exposure to the LW fungus or similar fungi in Asia. Redbay trees on the other hand have exhibited little or no evidence of resistance to the disease.



Figure 15. Camphor tree (Cinnamomum camphora) in McIntosh County, GA. Left: Dieback symptoms in June 2007 (Raffaella lauricola isolated by Stephen Fraedrich, USDA Forest Service), Right: same tree apparently fully recovered about one year later.

Other Insects and Diseases of Redbay

Black twig borer. Dead branchlets (flagging) on redbay caused by the black twig borer, *Xylosandrus compactus*, is very common, but has not been proven to be associated with LW disease. The black twig borer is another introduced Asian ambrosia beetle that is well established in the U. S. and attacks many tree species, including magnolia, sweetgum, hickory, holly, oaks, and many others including redbay. It kills small branchlets, but does not kill trees. Black twig borer damage was exceptionally abundant in coastal Georgia in 2007 and a special field visit was conducted on St. Catherines Island to confirm that abundant flagging on magnolia and other trees was indeed caused by *X. compactus*.

Debarking and damage to shoots cause by insect feeding. Patches of tender bark removed from branchlets (debarking) was commonly observed on redbay (Fig. 16). On some of the same branches, chewing damage was noted on leaf petioles and succulent new shoots, which sometimes died. This damage is similar to that caused by weevils on other plants. Similar debarking damage also was observed on young pondspice branches near Cloyo, GA. A large weevil identified as the avocado weevil, *Heilipus apiatus*, was also found on pondspice at this same site. This weevil is considered a pest on cultivated avocados in Florida. It has also been found on sassafras and has been suggested that its preferred host might actually be redbay (Hoffman 2003).



Figure 16. Patches of thin green bark removed by an unknown insect (possibly a weevil) on redbay branchlet, feeding also occurs on tender new growth causing wilted shoots and terminal dieback.

Stem cankers. Redbay trees with stems distorted by numerous cankers were observed on several plots, notably in Appling County Georgia (Fig. 17). Dead leaves and small branches were associated with these cankers, which at first led to some confusion as possible laurel wilt symptoms. However, branches tended to die from the bottom up leaving the tops of trees alive. Cutting into these cankers revealed pockets of black material.



Figure 17. Cankers on redbay under pine overstory in Appling County, Georgia. Cankers cause dieback from below with lower branches dying first leaving only the upper crown with green foliage.

Seed beetle. One instance of redbay fruits being attacked by the seed beetle, *Pagiocerus frontalis* (Fabricius) was observed in Richmond Hill, Georgia. In early September 2007, numerous seed beetles were observed boring into the fruits on a 4 inch diameter redbay tree in a residential neighborhood (Fig. 18). The tree had bumper crop of fruits and by September 20, nearly all had been attacked by seed beetles. In a sample of 219 fruits, 212 (97%) were infested.

This beetle is known to breed in fleshy seeds of several genera of Laurelaceae, notably *Persea* spp., and is widely distributed in lowland neotropical areas. In the U. S., they are found along the lower Gulf Coast and lower Atlantic seaboard to North Carolina. *Pagiocerus frontalis* has been reported to be a pest of farm-stored soft maize varieties grown in the high Andes of South America. Elsewhere in South America and in the Caribbean, it is known to breed on avocado seeds.

It is not known how common these seed beetles are in other areas, but heavy infestations could cause problems for gene conservation seed collections and regeneration of redbay and other laurel species.

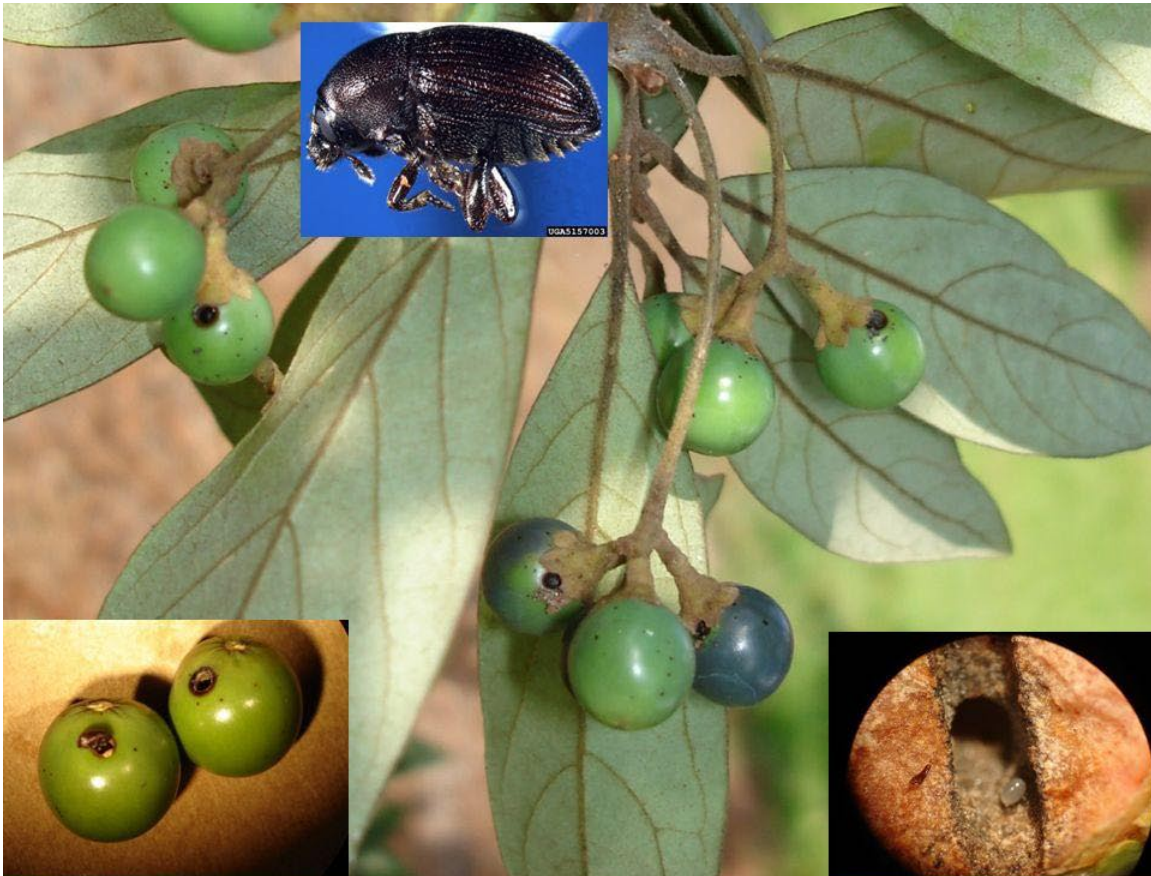


Figure 18. Seed beetle, *Pagiocerus frontalis*, attacking redbay fruit (drupe) in Richmond Hill, GA (9/9/2007). Bottom right: egg laid in gallery inside fruit cut in half.

Conclusions and Implications for Management, Research, and Future Monitoring

The systematic laurel wilt surveys conducted by the Georgia Forestry Commission in 2006 and 2007 along with supplemental observations have effectively documented the distribution and severity of laurel wilt disease in Georgia and provided insight into the rate and means of spread and possible future expansion of this devastating disease.

From the apparent original introduction of *X. glabratus* and *R. lauricola* in the Savannah area, laurel wilt disease has spread west and north in Georgia to areas of sparse redbay distribution in Screven, Jenkins, and Bulloch counties. Spread, in redbay, in this direction appears to have diminished significantly during the past couple years. However, many clumps of sassafras in fence rows and along highway rights of way have been diagnosed with laurel wilt disease near the leading edge of the general area of infection in Bulloch and Screven counties.

The most extensive recent expansion of the disease has been to the west and south along an irregular disease front with isolated infection centers found beyond the area of continuous disease. This pattern of disease progression is strongly suggestive of human-aided spread, including one disease incident initiated adjacent to a campground in Stephen Foster State Park, which most certainly resulted from redbay ambrosia beetles being transported in infested firewood by a camper.

Progression of the disease through the maritime forest on the barrier islands has been documented through periodic site visits by GFC personnel and observations of credible observers. The disease has now spread to all the major barrier islands in Georgia. The pattern of spread of laurel wilt through these islands and the gap in incidence on the mainland near the coast in Glynn and Camden counties strongly suggest a separate introduction of the disease in north Florida with the two fronts now converging in South Georgia.

Large expanses of water, marsh, swamps, and other areas where redbay is sparse or absent appear to have served as barriers to the continuous spread of the disease. Further expansion of laurel wilt in Georgia is likely to continue to the south and west into areas with relatively heavy concentrations of redbay.

Comparison of plots sampled in 2006 and 2007 revealed that average percent of infection in redbay trees more than doubled in one year in these plots, with mortality rates approaching 70 to 90 percent in the most heavily infected areas. However, significant numbers of mostly smaller diameter redbay trees along with numerous stump and root sprouts and smaller seedlings remain alive, even in the areas most heavily impacted by the disease. These remaining trees, seedlings and sprouts hold the promise for future survival and resurgence of redbay.

Estimates of the rate of spread during the past two years as well as that from the apparent original incidence of disease in the Savannah area to the present distribution in Georgia indicate that the natural spread rate has been about 10-15 miles per year.

Documentation of LW in sassafras in Bulloch and Screven counties provides an opportunity to observe whether or not the disease will transition to sassafras and continue to spread through the more extensive range of sassafras throughout much of the eastern half of the U.S.

Raffaelea lauricola was first isolated from a camphor tree in McIntosh County in Georgia. However, this tree recovered from initial dieback, suggesting the possibility of inherent resistance in this species which has common origins with the redbay ambrosia beetle and the laurel wilt fungus in Asia. In contrast, redbay is indigenous to North America and has exhibited little or no evidence of resistance to the disease. “The presence of laurel wilt in camphor provides an opportunity to understand the pathogen distribution and possible resistance mechanisms in this host which could have implications for efforts to remediate the impacts of the disease in redbay and other species in the Lauraceae in the southeastern United States” (J. A. Smith et al., in press).

Initial observations of mortality and isolation of the LW fungus from pondspice and pondberry raise concerns about the potential impact of this disease on these two rare species. More thorough sequential evaluations are needed to better characterize the damage and predict the potential impact of laurel wilt on these two plants.

The observation of a heavy infestation of redbay seeds by the seed beetle, *Pagiocerus frontalis*, on one tree near Savannah is not likely to be an isolated incident and indicates the need for further investigation to determine the potential impact on seed collections for gene conservation and natural reproduction of redbay.

The unabated spread of laurel wilt and devastating effects of this disease on mature redbay trees leave limited opportunities for management. However, the apparent human-assisted spread of laurel wilt observed in this survey underscores the urgent need to focus greater attention on limiting this pathway of dissemination. As outlined by the Laurel Wilt Working Group (2007), public education and outreach campaigns should emphasize the potential destructive consequences of moving firewood and raw materials infested with redbay ambrosia beetles to uninfested areas and should target those groups of people most likely to transport infested host material, including:

- Those who cut, utilize, transport or dispose of host tree material (e.g., tree service companies, utility companies, loggers, mulch plants, pulpwood mills, landfills, and transfer stations)
- Growers and sellers of live host trees (e.g., container and field nurseries, avocado growers)
- Owners of host trees in residential and landscape settings (e.g., homeowners, park managers, botanical gardens and arboretums)
- Owners and managers of host trees in forested and natural settings (e.g., forest landowners, forest and natural areas managers, park managers)
- Those who may transport firewood (e.g., hunters and campground visitors).

Research is needed to determine if redbay ambrosia beetles are capable of surviving and being dispersed in wood chips or bark mulch so that attention can be focused (or not) on this potential avenue of dispersal based on sound science.

The observation that wide areas devoid of redbay hosts may deter the spread of laurel wilt provides some evidence that the spread of the disease might be slowed or halted through elimination of host material, such as has been suggested around avocado production areas in south Florida (Laurel Wilt Working Group 2007). However, “no redbay” buffer zones would likely have to be complete and substantial, in the range of many miles, to prevent the natural spread of redbay ambrosia beetles.

Further monitoring projects should include surveys targeting the advancing disease front and beyond to document the spread of laurel wilt disease into new areas. However, areas already confirmed to have widespread laurel wilt infection would represent a low priority for future surveys. However, plots established in carefully selected areas within and just outside the general area of infection in which plant health is observed at periodic intervals would serve to document disease symptoms, local spread, and the ultimate fate of redbay, sassafras, pondberry, and pondspice in the expanding path of laurel wilt disease.

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