The potential for laurel wilt to threaten avocado production is real

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During 2002, the exotic redbay ambrosia beetle [*Xyleborus glabratus* (Xg)] was introduced into Port Wentworth, Georgia, U.S. By 2004, the link among Xg and its fungal symbiont [*Raffaelea lauricola*) *(Rf)*] the causal agent of the disease laurel wilt (LW) was confirmed. This insect-disease complex is indigenous to subtropical areas of Asia (e.g., Myanmar, Taiwan, Japan, and India) where it is associated with plants species in the Lauraceae [e.g., Asian spicebush, (*Lindera latifolia*)], Dipterocarpaceae (e.g., *Shorea robusta*), Fabaceae (e.g., *Leucaena glauca*) and Fagaceae (e.g., Lithocarpus edulis). In the Southeastern U.S., Xg and Raf have only been associated with plants in the Lauraceae. At least ten native plant species in Florida are LW hosts [e.g., Redbay (*Persea borbonia*) and swampbay (*P. palustris*)] and a potential host in California is the California laurel (*Umbellularia californica*). *Xyleborus glabratus* naturally disperses about 48 to 81 km per year through infestation of native host plants which suggests Xg could easily reach Ontario, Canada to the north and Texas to the west through natural habitats. However, laurel wilt was recently confirmed to be in Texas and thus threatens plants in the Lauraceae in Mexico and California. The potential for further spread of LW is due to the large number of potential native Lauraceae hosts and ambrosia beetle species on the American continent and the continued expansion of international trade and travel. This could have profound ecological consequences for native Lauraceae throughout North, Central and South America and commercial avocado production throughout the western hemisphere.

Raffaelea lauricola was first detected in north Florida (Duval County) in 2005 and by 2006 had spread to central Florida. The vector of LW, *Xyleborus glabratus* was first detected in a natural area about 32 km north of south Florida's commercial avocado production area in March 2010. By February 2011 LW was confirmed in dying native swampbay (*P. palustris*) trees and by February 2012, LW had been confirmed in a commercial avocado orchard. Several other ambrosia beetles (AB) species, *X. volvulus* and *X. ferrugineus* are now known to carry *Rf* and appear to be more important vectors under orchard conditions. Although AB are responsible for short and long distance movement of the pathogen, the most rapid spread in an orchard is via pathogen transmission through grafted roots among adjacent avocado trees. Recommendations for control of LW include: (1) early detection of *Rf* affected trees by frequent scouting of orchards; (2) sampling suspect trees for the pathogen; (3) tree uprooting, chipping of all wood possible and burning wood too large to chip and; (4) treatment of wood chips with insecticides. Additional recommendations include prophylactic infusion of propiconazole into avocado trees adjacent to infected trees or all trees in the orchard and periodic aerial insecticide applications to reduce AB populations.

Florida's relatively small (~3,035 ha) but valuable (US$100 million) avocado industry has been impacted by LW. To date the death of approximately 9,500 commercial avocado trees may be attributed to LW with at an estimated loss of US$3.5 million. Short-, mid- and long-term research on the control of *Rf* and AB is on-going.

Key words: Scolytinae, Xyleborini, Curculionidae, Ascomycetes, *Ophiostoma*

INTRODUCTION

Florida's commercial avocado industry is located in a 324 sq. km area at the extreme southern end of the peninsula in Miami-Dade County. The industry is comprised of about 3,035 ha and has an economic impact of US$100 million (Evans and Lozano, 2014). There are approximately 450 commercial producers (A. Flinn, personal communication).

Laurel wilt is a lethal vascular disease affecting woody plants in the Lauraceae in the southeastern U.S. The laurel wilt vector, the redbay ambrosia beetle, *Xyleborus glabratus* and pathogen, Raffealea lauricola are indigenous to Southeast Asia (e.g., Indian, Japan, Myanmar, and Taiwan) where they attack trees in the Lauraceae (e.g., *Litsaea elongata*), Dipterocarpaceae (e.g., *Shorea robusta*), Fagaceae (Lithocarpus edulis), Fabaceae (e.g., *Leucaena glauca*) and Moraceae (Harrington *et al.,* 2011; Rabaglia, 2006; Smith and Spence, 2010). In the U.S. only woody plants in the Lauraceae have been reported to succumb to LW.

The redbay ambrosia beetle (*Xyleborus glabratus*) was first detected in a survey trap in Port Wentworth, Georgia during 2002 (Fig. 1; Mayfield and Thomas, 2006). Relatively soon afterward the association between extensive mortality of redbay (*Persea palustris*) and sassafras (*Sassafras albidum*) trees throughout Georgia and north Florida and Xg and its fungal symbiont *Rf* became apparent (Fraedrich *et al.,* 2007; Fraedrich *et al.,* 2008; Harrington *et al.,* 2008; Rabaglia *et al.,* 2006). The first instance of the susceptibility of avocado trees to *Rf* was in 2007 in north Florida (Jacksonville, Duval Co.) (Mayfield *et al.,* 2008). The movement of laurel wilt throughout the Florida peninsula was relatively rapid and was presumably aided by anthropogenic movement of redbay ambrosia beetle infested wood products (e.g., logs for firewood and wood-turned items) (Fig. 1). In 2010 Xg was first detected in a natural area about 32 km north of south Florida's commercial avocado production area and by February 2011 LW was confirmed in dying native swampbay (*P. palustris*) trees (Thomas, 2010; Ploetz *et al.,* 2011). In February 2012, LW had been confirmed in a commercial avocado orchard in Homestead, Florida (Ploetz *et al.,* 2011; FDACS, 2012; A. Palmateer, 2012). At present laurel wilt has been confirmed in eight states (Alabama, Georgia, Florida, Mississippi, North Carolina, South Carolina, and Texas) and 59 of 67 Florida counties (Fig. 2) (Bates *et al.,* 2015; Gardner *et al.,* 2015).

Hosts and impact of laurel wilt

World-wide the Lauraceae is comprised of approximately 68 genera and 3,000 mostly woody species distributed throughout tropical and subtropical regions of Southeast Asia and tropical America (Sampson, 2015; Plant List, 2015). Known hosts of Xg and *Rf* are relatively few but include a number of species from Asia, the American continent and Macaronesia (Table 1).

In the U.S., some forest host species such as redbay (*Persea borbonia*), swampbay (*P. palustris*), sassafras (*Sassafras albidum*) and California laurel (*Umbellularia californica*) are widespread (Fig.3). A recent analysis of the potential effect of laurel wilt on native Lauraceae in the U.S. list four species as vulnerable to extirpation or extinction (Lindera melissafolia (pondberry), Lindera subcoriacea (bog spicebush), Litsea aestivalis (pondspice), and *Persea* humilis (silkbay) (Gramling, 2010). An estimated nine of 56 native plant communities in the U.S. where a member of the laurel family is dominant or diagnostic for the community was designated as critically imperiled due to laurel wilt. Some effort has been made to relocate and/or collect seed from some endangered species (e.g., Litsea aestivalis) for long-term storage (Surdick and Jenkins, 2010).

Swampbay trees (*Persea palustris*) play a critical role the tree island ecosystem in Everglades National Park and Big Cypress Preserve (Rodgers *et al.,* 2014). They provide critical upland habitat for wildlife, biogeochemical cycling (e.g., phosphorus), and increase peat accretion rates. Over a two year period (2011 to 2013) an aerial survey of tree islands for laurel wilt affected swampbay trees found the range of laurel wilt symptomatic swampbay trees had increased from a 4925 ha range of occupancy in the eastern Everglades to 133740 ha range in 2013 (Rodgers *et al.,* 2014). The western edge of the laurel wilt focus had expanded about 53 km in two years which is about one half the predicted rate of the spread of 54.8 km per year by Koch and Smith, 2008. The ecological impacts of laurel wilt on swampbay tolerance to periodic flooding and fire survival and in turn swampbay's impact on wildlife may soon become apparent (Snyder, 2014). In addition the loss of bay laurel (*Laurus nobilis*) for ornamental purposes may have a negative impact on the nursery and landscape trade as well.

Avocado trees are susceptible to attack by the redbay ambrosia beetle and succumb to laurel wilt (Mayfield *et al.,* 2008a; Mayfield *et al.,* 2008; Peña *et al.,* 2012; Ploetz *et al.,* 2011). However, over a six year period only about six Xg have been captured in commercial avocado orchards and current research confirms *Rf* contaminated about seven other ambrosia species and two, *X. volvulus* and *X. ferrugineus* have been shown capable of transmitting *Rf* (Carrillo *et al.,* 2014; Carrillo *et al.,* 2012). Laurel wilt was first detected in the northeastern quadrant of Florida's 324 sq km commercial production area in 2012. Since that time, the percentage of positive *Rf* disease samples submitted to the UF/IFAS TREC Diagnostic Clinic increased from 32% in 2012 to 43% in 2013 and 62% in 2014 (A. Palmateer, personal communication). This does not account for LW symptomatic trees not sampled in orchards where LW has been documented previously. Rough estimates of the tree mortality attributed to LW per year are 250, 2250, 3500 and 3500 for 2012, 2013, 2014 and 2015 (to date), respectively (D. Pybas and J. Crane, personal communication). Thus the loss of roughly 9500 trees (about 38 ha) or about 1.3% of all the commercial trees may be attributed to LW; estimated value, US$3.1 million (Evans and Crane, 2013).

The potential for LW expansion outside the S.E. United States

There are several reasons to believe that LW will continue to spread throughout many areas of the U.S. and potentially to Mexico and Central and South America. These include available native lauraceous host plants throughout the hemisphere (e.g., Table 1; van der Werff, 1991, 2002a, 2002b), the relatively short life cycle and time to host emergence of Xg (about 60 days after gallery initiation) (Brar *et al.,* 2013), survival of Xg (inside trees) in areas with at least occasional freezing temperatures, e.g., North Carolina, an estimated 39 Xyleborina species in the U.S. (Rabaglia *et al.,* 2006) and 3400 worldwide (Farrell *et al.,* 2001), the often cryptic nature (i.e., may go undetected for long periods of time) of ambrosia beetles, the relatively large number of ambrosia species (at least 14 species) capable of breeding in or attacking avocado (Carrillo *et al.,* 2012; Kendra *et al.,* 2011), the potential for additional lateral transfer of the pathogenic *Rf* symbiont to native and exotic ambrosia beetles then capable of transmitting *Rf* (Carrillo *et al.,* 2013), the large host range of many ambrosia beetle species, and the potential for natural (~55 km per year; Koch and Smith, 2008) and more importantly anthropogenic movement of ambrosia beetles to new areas.

Trade throughout the world has continued to increase despite the economic downturn from 2007-2011 (Hongbo *et al.,* 2015). A recent analysis of the association among international trade and environmental factors on the establishment of exotic Scolytinae in the U.S. found minimum temperatures, value of imports and precipitation explained 71-73% of the variation in the three models tested (Marini *et al.,* 2011). In another study, a positive relationship between the number of scolytid interceptions at U.S. ports of entry from individual countries and the value of their imports was found over a sixteen year period (1985-2001) (Haack, 2001). During this period 6992 Scolytidae were intercepted; 73% from wood packaging. Treatments (e.g., fumigation and heat) to disinfest wood packaging has been implemented to reduce insect and disease introductions through trade; however, this has not been evaluated.

Currently laurel wilt has been detected in eight U.S. states (moving north to south/east to west), North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas (Bates *et al.,* 2015; Fig. 2). In almost every instance (except Georgia to South Carolina) the spread of laurel wilt to new areas was much faster than the natural spread predicted by Koch and Smith (2008) and must have been anthropogenically assisted. Even without the human assistance, distribution maps of redbay, swampbay, and sassafras show the potential path of spread through the natural areas from Georgia (site of original introduction) to southeastern Texas (Fig. 3). Potentially native lauraceous hosts of laurel wilt may allow the spread of laurel wilt into California (Fig. 3), Mexico, Central and South America. In addition, the possibility for *Rf* to be laterally transferred to additional ambrosia beetles species may facilitate and/or accelerate the spread of this devastating insect/disease complex. Thus it's reasonable to believe laurel wilt represents a major threat to native trees in the Lauraceae and commercial avocado production throughout the Western Hemisphere. Furthermore, the presence of Xg/*Rf* may also limit commercial avocado production in some areas of Asia (e.g., Myanmar) in the future (Ploetz, *et al.,* 2015).

Avocado cultivar *Rf* tolerance

To date 16 avocado cultivars exposed to Xg under controlled conditions have been attacked (Mayfield *et al.,* 2008; Peña *et al.,* 2012). However, there is some indication that despite Xg attack of 'Hass' avocado under controlled conditions with containerized plants, this did not result in LW symptoms (e.g., wilted and discolored sapwood) and *Rf* was not recovered from the sapwood (Peña *et al.,* 2012). Ploetz *et al.,* (2011) evaluated 24 avocado cultivars of varied genetic background and found those of Guatemalan x Mexican background (e.g., 'Hass', 'Winter Mexican') were less affected by *Rf* inoculation than avocado cultivars of Guatemalan x West Indian (e.g., 'Miguel') background which were more tolerant than West Indian (e.g., 'Simmonds and 'Donnie') cultivars. This suggests there may be some variability in LW tolerance dependent upon genetic background. In addition, symptom severity was positively correlated with plant size, meaning larger plants react more strongly to the presence of *Rf* than smaller plants. However, *Rf* has been documented to kill mature plants under orchard conditions of not only West Indian background (e.g., 'Simmonds' and 'Bernecker') but of Guatemalan x West Indian (e.g., 'Choquette'and 'Monroe'), Guatemalan (e.g., 'Marcus Pumpkin') and Guatemalan x Mexican (e.g., 'Winter Mexican') backgrounds (Table 2) (A. Palmateer and J. Crane, personal communication).

SUMMARY

Laurel wilt is threatening the Florida avocado industry and continues to spread to new areas and states. Based on the biology and behavior of ambrosia beetles and the *Rf* pathogen and the proliferation of potential lauraceous hosts in North, Central and South America there is a real potential for laurel wilt to spread to Mexico and Central and South America via natural movement of ambrosia beetles through natural habitats. In addition, there is potential for human transport of LW as trade and travel increase.

A holistic management approach for LW and its ambrosia beetle vectors has been underway for some time (since ~2006). However, although there are tactics which slow the spread of LW in Florida's commercial production area they are expensive (E. Evans, personal communication) and if not well or widely implemented not wholly efficacious (see Crane *et al.* in these proceedings). New management strategies are under development including suppressing ambrosia beetle populations (e.g., bio-control, trap and kill systems), testing of longer-lasting and more efficacious fungicide application methods and materials, and determining what potential effect avocado rootstock may have on tolerance to laurel wilt (Ploetz *et al.,* 2015).

Recommendations to avocado industries in Latin America and elsewhere

1. Identify native hosts of laurel wilt and their distribution and implement a systematic and on-going monitoring program to identify trees suspect for laurel wilt.
2. Train plant diagnostic centers in assays for detecting and reporting laurel wilt pathogen positive plants to local regulatory agencies and academic institutions quickly.

Support research to determine which native ambrosia beetles may become contaminated with *Raffaelea lauricola* and accelerate the spread of laurel wilt.

3. Develop a quick response plan to attempt either eradication or containment of a laurel wilt outbreak.
4. Support research to identify native and avocado laurel wilt hosts and management.

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Table 1. Trees in the Lauraceae and known hosts of the redbay ambrosia beetle and/or the laurel wilt pathogen

Common name	Scientific name	Citationy
	Native to the U.S.	
Gulf licaria	*Licaria trianda*	Ploetz and Konkol, 2013
Northern spicebush	*Lindera benzoin*	Fraedrich *et al.,* 2008
Pondberry	*Lindera melissafolia*	Fraedrich *et al.,* 2011
Pondspice	*Litsea aestivalis*	Fraedrich *et al.,* 2011
Redbay	*Persea borbonia*	Fraedrich *et al.,* 2008
Silkbay	*Persea* humilis	Hughes *et al.,* 2012
Swampbay	*Persea palustris*	Fraedrich *et al.,* 2008
Sassafras	*Sassafras albidum*	Fraedrich *et al.,* 2008
California laurel	*Umbellularia californica*	Fraedrich, 2008; Mayfield *et al.,* 2013
	Native to Mexico, Central and/or South America	
Avocado	*Persea americana*	Mayfield *et al.,* 2008ab
------	*Persea* caerulaz	Peña *et al.,* 2012
------	*Persea cinerascens*	Peña *et al.,* 2012

Common name	Scientific name	Citationy

------	*Persea* nubigienaz	Peña *et al.*, 2012
------	*Persea* skutchiiz	Peña *et al.*, 2012
------	*Persea* tilarensisz	Peña *et al.*, 2012
------	*Persea* tolimanensisz	Peña *et al.*, 2012
	Native to Asia	
Camphor	*Cinnamomum camphora*	Smith *et al.*, 2009; Fraedrich *et al.*, 2014
Bay laurel	*Laurus nobilis*	Hughes *et al.*, 2014; Hansen, 2011
Asian spicebush	*Lindera latifolia*	Rabaglia *et al.*, 2006
Yellow litsea	*Litsaea elongate*	Rabaglia *et al.*, 2006
	Machilus nanmu	Hulcr and Lou, 2013
	Phoebe lanceolate	Rabaglia *et al.*, 2006
	Phoebe zhennan	Hulcr and Lou, 2013
	Phoebe neurantha	Hulcr and Lou, 2013
Sal	*Shorea robusta*	Rabaglia *et al.*, 2006
	Native to Macaronesia	
	Persea indica	Hughes *et al.*, 2013

y, See literature cited; z, Taxonomy unresolved.

Table 2. Thirty-five avocado cultivars confirmed positive for the laurel wilt pathogen either under orchard and/or container-grown conditionsz

Cultivars positive for *Rf* under orchardconditions	Race[y]	Cultivars positive for *Rf* under orchard conditions	Racey	Cultivars testing positive for *Rf* under greenhouse conditions only	Racey
Bernecker*	WI	Miguel*	G-WI	Catalina	WI
Day*	WI	Monroe*	G-WI	Trapp	WI
Donnie*	WI	Tonnage*	G-WI	Ettinger	G-M
Pollock*	WI	Tower-2	G-WI	Pinkerton	G-M
Waldin*	WI	Loretta	G-WI	Hass	G-M
Hardee	WI	Nadir	G-WI	Reed	G
Dupuis*	WI	Booth 7	G-WI	Bacon	G
Russell*	WI	Booth 8	G-WI		
Simmonds*	WI	Brooks Late	G-WI		
Nesbitt	G-WI	Brogdon*	G-M-WI		
Beta*	G-WI	Marcus Pumpkin*	G		
Choquette*	G-WI	Winter Mexican*	G-M		
Hall*	G-WI	Toni	Nd		
Lula*	G-WI	Jim Lapeck	Nd		

*Container-grown plants also tested positive for laurel wilt; Nd, not determined.

y, WI, West Indian (Antillean); G, Guatemalan and; M, Mexican.

z, A.J. Palmateer, Dir., UF/IFAS Plant Diagnostic Clinic, TREC, Homestead, FL; J.H. Crane and R.C. Ploetz, UF/IFAS TREC, Homestead, FL; Ploetz, R.C., J.M. Pérez-Martínez, J.A. Smith, M. Hughes, T.J. Dreaden, S.A. Inch, and Y. Fu. 2011. Plant Pathology doi: 10.1111/j.1365-3059.2011.02564.x; Peña, J.E., D. Carrillo, R.E. Duncan, J.L. Capinera, G. Brar, S. McLean, M.L. Arpaia, E. Focht, J.A. Smith, M. Hughes and P.E. Kendra. 2012. Fla. Ent. 95:783-787; Mayfield, A.E., III, J.E. Peña, J.H. Crane, J.A. Smith, C.L. Branch, E.D. Otsoson and M. Hughes. 2008b. Fla. Ent. 91:485-487.

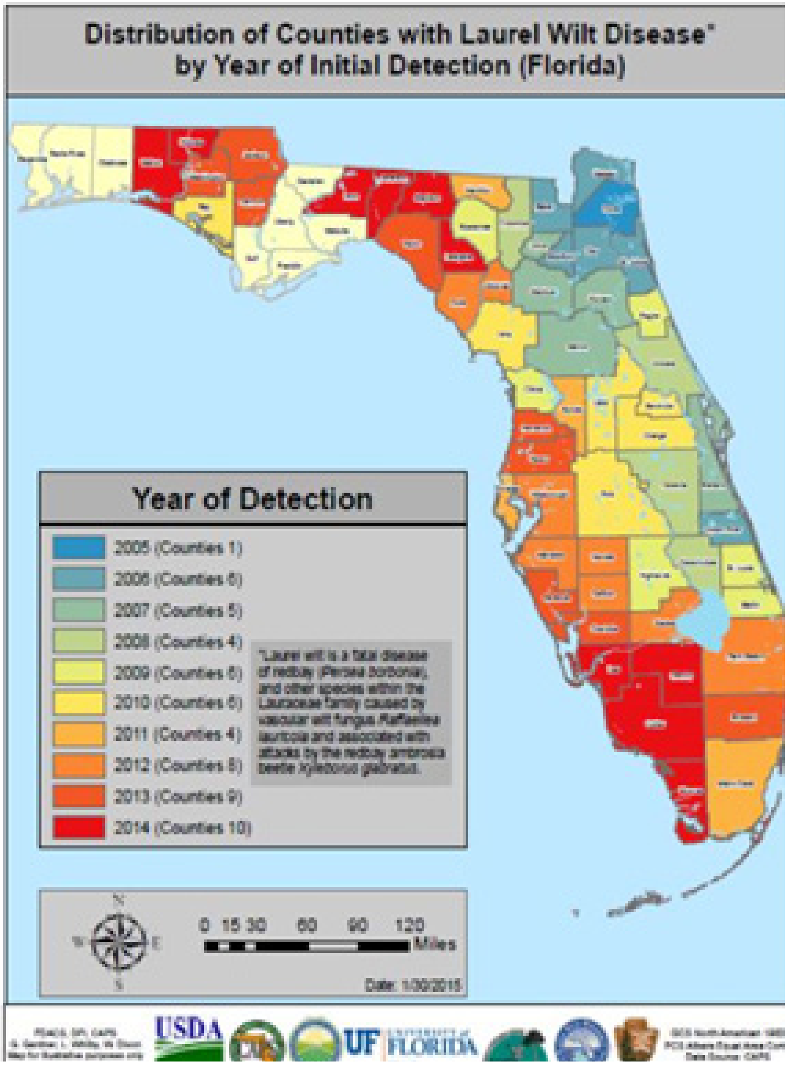

Fig. 1. Distribution of Florida counties with laurel wilt disease by year and initial detection (Bates et al., 2015).

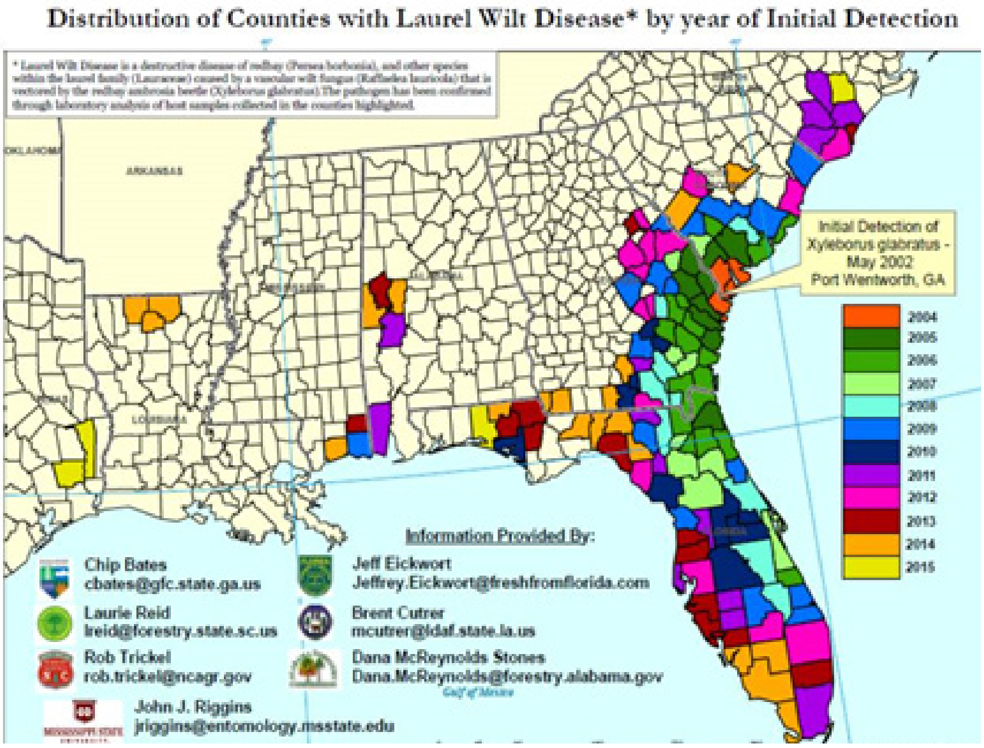

Fig. 2. Distribution of counties and states with laurel wilt disease by year of initial detection (Gardner et al., 2015).

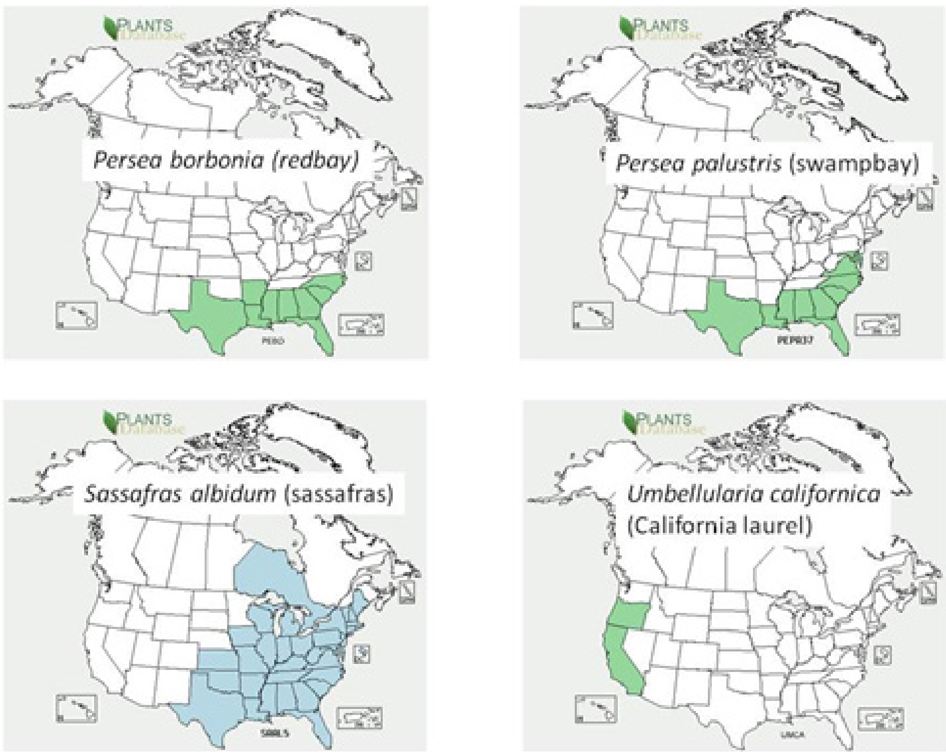

Fig. 3. Distribution maps of native Lauraceae in the U.S. (USDA, Natural Resources Conservation Service, Plants Database, http://plants.usda.gov/gallery.html).

ACTAS · PROCEEDINGS

VIII CONGRESO MUNDIAL DE LA PALTA 2015

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