Landscape Disease Symposium

Tuesday January 16, 2018

Hansen Agricultural Research and Extension Center

14292 West Telegraph Road

Santa Paula CA 93060

University of California
Agriculture and Natural Resources

Landscape Disease Symposium

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Agenda

7-8 am
Registration: - Jim's Coffee

8-9 am

Botryosphaeria Canker of Landscape Trees: an Increasing Landscape Disease in Southern California—Pages 3-7

James Downer Ph.D. University of California Cooperative Extension, Ventura County

9-10 am

Understanding the Biology of Annulohypoxylon, Biscogniauxia, and Hypoxylon: Saprotting Ascomycete Pathogens of Hardwoods in Southern California—Pages 8-11

James Downer Ph.D. University of California Cooperative Extension, Ventura County

10-10:30 am

Fungi Identified from Failed Stems and Branches of Urban Trees– Pages 12-13

Igor Lacan Ph.D. University of California Cooperative Extension San Mateo and San Francisco Counties

10:30-11 am
Break
11 am-Noon

Elucidating "lucidum": Distinguishing the Many Faces of ' Ganoderma lucidum' in the United States—Pages 14-23

Andrew L. Loyd Ph.D. candidate, University of Florida

Noon-1 pm
Lunch
1-2 pm

Laurel Wilt: an Emerging Threat to the Lauraceae in the United States– Page 24

Andrew L. Loyd Ph.D. candidate, University of Florida

2-3 pm

Tree Disease and Wood Decay as Agents of Environmental and Social Change– Pages 25-30

Keven T. Smith Ph.D. U.S. Forest Service, Northern Research Station, Durham New Hampshire

3-3:30 pm

Break
3:30-4:30 pm

New to California: Diseases of common Landscape Plants—Pages 31-36

Drew Zwart Ph.D. Bartlett Tree Company

Jim Downer

Plant Pathology Advisor

University of California Cooperative Extension

Botryosphaeria Canker of Landscape Trees: an Increasing Landscape Disease in Southern California

Botryosphaeria is the genus name for a variety of Ascomycete fungi found in the fungal order Botryosphaerales. Due to the advent of modern molecular tools used for creating phylogenies, many fungi previously known as *Diplodia, Macrophoma, Phoma, Dothiorella, Fusicoccum, Neofusicoccum, Phylosticta* and *Sphaeria*, are now “correctly” named as *Botryosphaeria*. The pathogen and its species are widespread on all continents except Antarctica and comprise hundreds of species affecting hundreds of woody hosts. The pathogenic species *B. dothidea* has also been identified as an endophyte existing in plant tissues without any apparent disease symptoms (Perez and others, 2010).

Botryosphaeria causes canker symptoms on infected trees. Cankers are visible dead areas of stems, branches or trunks that can develop in the cambium and bark or both the xylem and phloem, sometimes the pathogen grows deep into woody tissues. Cankers may begin at a wound or branch stub or at the axis of a twig and branch. Canker fungi girdle stems by killing the cambium as they grow around the circumference of the stem. They also may grow very rapidly longitudinally in the phloem, cambium or wood and move from smaller to larger branches as the pathogen proceeds toward the main stem or trunk. Cankers can spread by infection of new branches as the fungus grows down the xylem and around branch collars, or by development of fruiting bodies which produce spores spreading new infections within the tree or tree to tree. Spores can also be moved with waste or trimming equipment. Large branches and the main stem may take years to girdle and ultimately die. Continued spread of cankers and formation of new cankers, often leads to death of the entire tree or shrub if stress is also present.

Canker growth rates depend largely on what kind of canker disease is caused and this is related to the genetics of host resistance and pathogen virulence. Manion (1990) defined cankers diseases as a continuum or relationships between host and pathogen from host dominant to pathogen dominant. These are annual, perennial and diffuse cankers. *Botryosphaeria* likely causes all three canker types depending on the host they are infecting and other predisposing factors. Cankers diseases are either pathogen dominant or host dominant or variations of the two. In a pathogen dominant canker, the host has little resistance to it and the stem will soon die as the canker causes a girdle. Diffuse cankers are pathogen dominant, aggressive and deadly to the host. Annual cankers are pathogenic but the host has the ability to overcome them with new tissue growth and they can be held in check. Perennial cankers grow each year but the host limits fungal growth by developing callus tissues which are not immediately susceptible to the pathogen--the canker remains dormant for part of the year. The canker pathogen eventually overcomes host resistance and enlarges. This results in a classic target-like lesion in the tree. Many perennial target cankers are neither completely host nor pathogen dominant but somewhere in-between. Tatter (1978) notes that most cankers are bark diseases, but that some pathogens also invade the sapwood and he terms these as canker rots. *Botryosphaeria* seen in landscape plants in Southern California appears to infect far into the xylem (Fig. 1).

Botryosphaeria dothidea causes extensive disease in over 50 native species or cultivars of California native plants (Brooks and Ferrin, 1994.) Brooks and Ferrin as well as others associated outbreaks of *Botryosphaeria* related disease to drought conditions over a number of years leading to widespread disease. Earlier work by Crist and Schoeneweiss (1975), showed increased susceptibility in *Betula alba* to *B. dothidea* in response to decreasing water potentials. Similar results were shown by Ma and others (2001) in Pistachio (2001). So the main message is that drought predisposes trees to attack by *Botryosphaeria*. After years of drought, more *Botryosphaeria* is seen and the number of cankered trees increases as a result of years of predisposing drought stress.

Increased and prolonged droughts in Southern California may explain the widespread outbreak of *Botryosphaeria* diseases in *Ficus microcarpa* throughout Southern California. This disease is caused by a number of different *Botryosphaeria* species (Mayorquin et al, 2012). Cankers typically discolor wood to the central xylem or pith. Little is known about the spread and infection requirement of Ficus branch disease, but it seems likely that it is spread by pruning equipment as Indian Laurel Fig is frequently and extensively pruned as a street tree (Fig. 2).

Botryosphaeria also causes disease in coast live and other oaks as *Botryosphaeria stevensii* (formerly *Diplodia quercina*) Swiecki and Bernhardt (2006). Increased infection in oaks was reported following the severe droughts of 1976-1977. In Ventura we have seen increased disease in Mayten Trees struggling with *B. iberica* (Fig. 3). These are usually observed in non-irrigated parkways as street trees or in dry landscapes. Even though a species such as *Maytenus boaria* is drought tolerant, this disease can take advantage of these trees during dry times.

Gymnosperms are also very susceptible to *Botryosphaeria dothidea.* Redwood, Giant Sequoia, and incense cedar are all very susceptible to the pathogen when grown as landscape trees. Disease usually occurs when trees are grown outside their native range where they endure low humidity, excessive heat drought or saline irrigation water(Fig. 4, 5). Coupled with specimen growing habits (as opposed to forest growth habit) and excessive pruning, the disease can be particularly destructive. *Sequoia gigantea* can rarely be grown to maturity outside its native mountain ranges before the pathogen kills the tree by cankering branches and main stem.

Disease control is best achieved by respecting plant adaptations and not growing poorly adapted plant materials. Avoiding drought by irrigating trees during dry summers or during periods of drought will prevent the stress that usually predisposes trees to attack from *Botryosphaeria* fungi. There are fungicides that are effective against the "Bot" fungi, but they would only protect from infection, not cure established cankers. As will all canker diseases, pruning out cankered branches is a way to slow disease progress. In some cases plant defenses slow the progress of the disease—*Ficus microcarpa* slows the progress of disease at the Branch collar (Figure 6.). It is not known that pruning spreads the disease but it is likely as shown here (Fig. 2) where disease spread around a corner of street trees but not across the street as pruning cycles likely are different on different streets. Sanitation of pruning equipment between trees may limit spread of the disease in street tree situations.

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Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

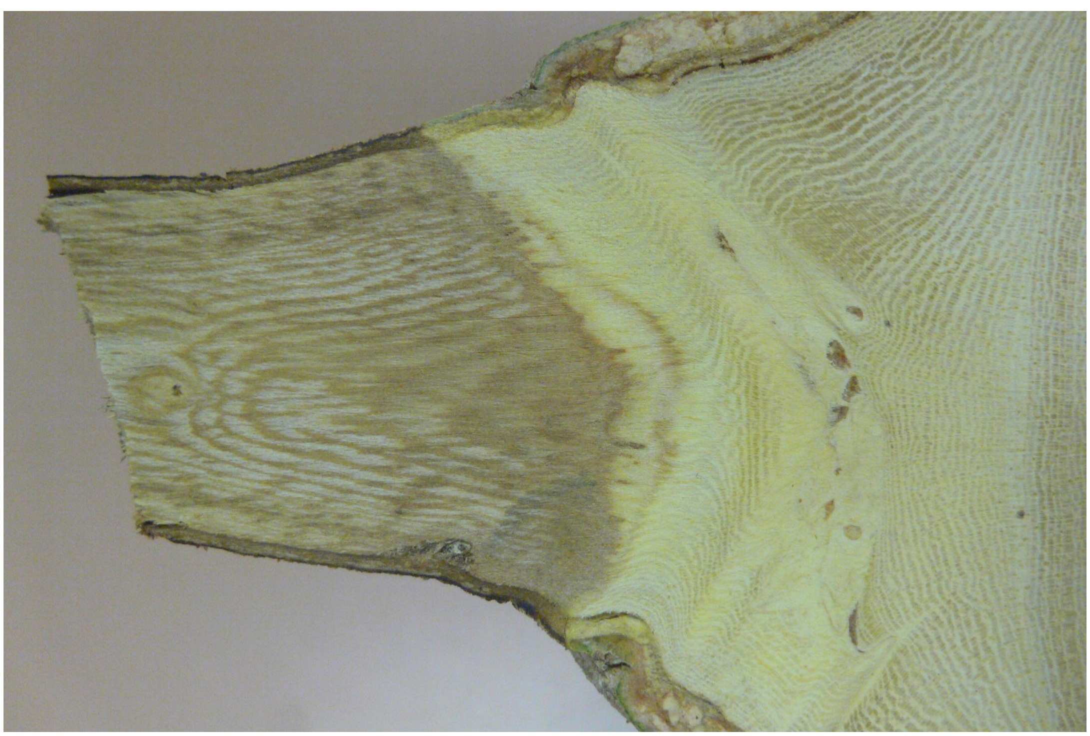

Fig. 6

Jim Downer

Plant Pathology Advisor

University of California Cooperative Extension

Understanding the Biology of *Annulohypoxylon*, *Biscogniauxia* and *Hypoxylon*: Saprotting Ascomycete Pathogens of Hardwoods in Southern California

Hypoxylon, Annulohypoxylon, Biscogniauxia, and *Kretzschmaria* are all members of the order Xylariales class Sordariomycetes, and division Ascomycota. Many of the fungi in Xylariales are decay causing or saprophytic organisms. Their role is to break down wood in the production of forest litter. Some members of the order begin this task early while the tree is still standing or still living and as such, can be considered pathogenic. These fungi enter through wounds and invade the sapwood of living trees. They can grow rapidly in predisposed trees causing extensive sap rot, cankers and branches or the main stem, and death of large sections of the vascular cambium. After sapwood and cambial tissues die, the fungi typically fruit in the dead tissue, producing an initially light colored stroma that produces asexual cells (conidia). The fruiting bodies may appear grey or tan in color. This phase gives way to a dark charcoal black stroma containing sexual fruiting bodies (perithecia) which in turn contain the sexual spores (ascospores). *Kretzchmaria* in the Southern United States, typically produces its conidial stroma in the winter and perithecial stroma in the summer (Sinclair et al., 1987). The stroma of *Hypoxylon* or *Annulohypoxylon* are globular while those of *Biscogniauxia* and *Kretzschmaria* occur in longitudinal sheets under the bark (Fig 1&2a,b). These Xylariales seem to replace the vascular cambium with developing stroma. So that if stroma are seen, you can generally be sure that this portion of the tree is dead.

These fungi prefer hardwoods such as Oak, Maple, Sycamore, Pecan, etc. These pathogens (especially *Biscogniauxia*) prefer oak particularly the red oak subgroup (Olson, 2017). Mature trees are often affected, while saplings or young trees are not commonly attacked. Predisposition to disease can occur from fires, drought stress, and attack by other pathogens. They are usually not primary pathogens but attack declining and otherwise stressed trees. Anything that compromises the root system can create conditions for expansion of the Xylariales.

Members of the Xylariales cause decay in standing trees, usually classified as a white rot in most cases. Schwarze (2008) asserts that *Kretzschmaria* can cause a soft rot, which while not an aggressive lignin destroyer, does cause extensive decay in the sap wood of standing trees. Because the group leaves a lignin "skeleton" behind, the wood becomes brittle and can lead to hazardous conditions in trees. *Kretzschmaria*, (extensively studied by Schwarze) is also able to drill through reaction zones imposed by trees and penetrate ray parenchyma, which usually limits movement of such organisms.

Infection occurs through wounds or breaks in the xylem. Initially the fungus may be slow to colonize the sapwood and may linger in a non-pathogenic phase for many years. When stress occurs, the pathogen grows aggressively up and down major branches or the main stem of the tree, causing discolored wood (figure 3). A canker forms under the bark, where (eventually when the cambium dies) a stroma (thick cushion like mat of hyphae) is formed that pushes the bark from the tree revealing itself as a tan to black fruiting body. In fire affected trees, the stroma may be difficult to see as it looks like charcoal. By the time the stroma forms, the fungus has likely caused a sap rot and the wood of major branches may have signficant strength loss if there are accompanying heart rot fungi in the tree.

Biscogniauxia mediterranea is known as an endophyte in oak and has been detected in non-symptomatic tissues of *Quercus* (Vannini, et al., 2008). Swiecki and Berhardt (2006), describe a similar process for *Annulohypoxylon thousarianum*. *Biscogniauxia* appears to be more detectable when water potentials in the stem are decreased. This suggests that infection is tied to drought (Fig 4). The endophytic lifestyle of xylariales fungi may simply be a waiting period for the host to senesce or hasten the aging process before becoming pathogenic (Petrini et al., 1995). Schwarze also indicates that sapwood pathogens tend to have a rapid invasion strategy (which would be analogous to the endophytic phase) and that they do not cause decay until the wood dries out partially (drought). Some of the Xylariales such as *H. thousarianum* fruit abundantly in *Phytophthora ramorum* infected trees. The life style phase shift of *Biscogniauxia* and other Xylariales from endophyte to parasite to sapwood decay organism is likely mediated by edaphic factors primarily drought, but also root injury or disease caused by other pathogens.

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Fig. 1

Fig. 2 a

Fig. 2 b


Fig. 3


Fig. 4

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Wood Decay Fungi Found in Failed Wood

Study description: While tree failure (breakage of roots, trunk, or branches) has many causes, the extent to which wood-decay fungi contribute to failure is unknown, especially in the early stages of fungal infection, when no decay is visible. In this study, we are testing failed wood – broken branches, trunks, and roots – for presence of fungal DNA at the point of failure. The DNA test, developed by Matteo Garbelotto's lab, can detect 22 species of wood decay fungi, as well as indicate if some other (unidentifiable) species of fungus is present.

Goals: The near-term goal is to assess the presence and species composition of fungi in failed wood; the ultimate goal is to inform tree risk-assessment process, by providing the arborist information on which fungal species are associated with tree failure (so that a standing tree can be tested for the presence of those fungi).

Results:

105 Samples received

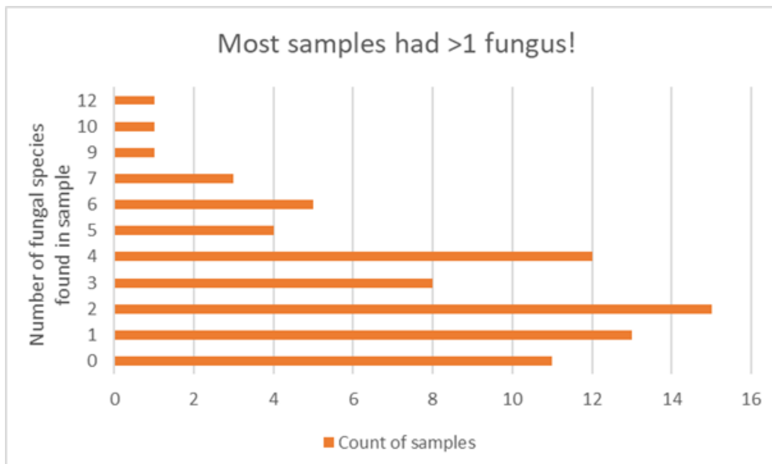
74 samples processed

Only 11 samples without identified fungus!

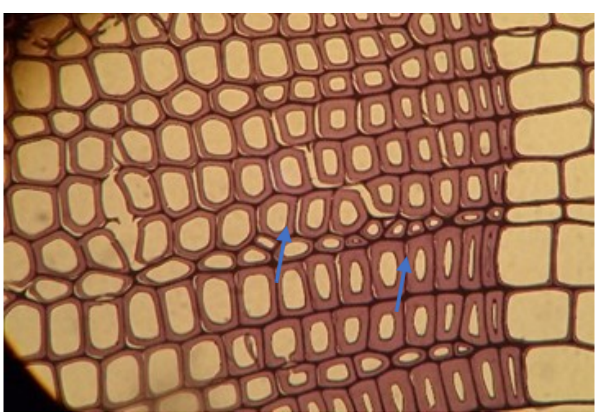
Median: 5 fungi per sample!

Maximum: 12 different fungi in a single sample!

Species found: *Armillaria, Fomitiporia, Fuscoporia, Ganoderma, Hericium, Inonotus, Laetiporus, Oxyporus, Perenniporia, Phellinus, Pleurotus, Pseudoinonotus, Sarcocladium, Schizophyllum, Stereum.*

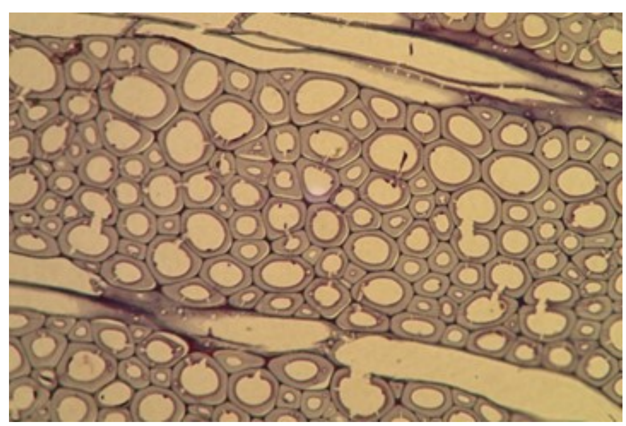


Notable findings (thus far): ~ Many saprot-fungi found; ~ Brown rot more common than expected



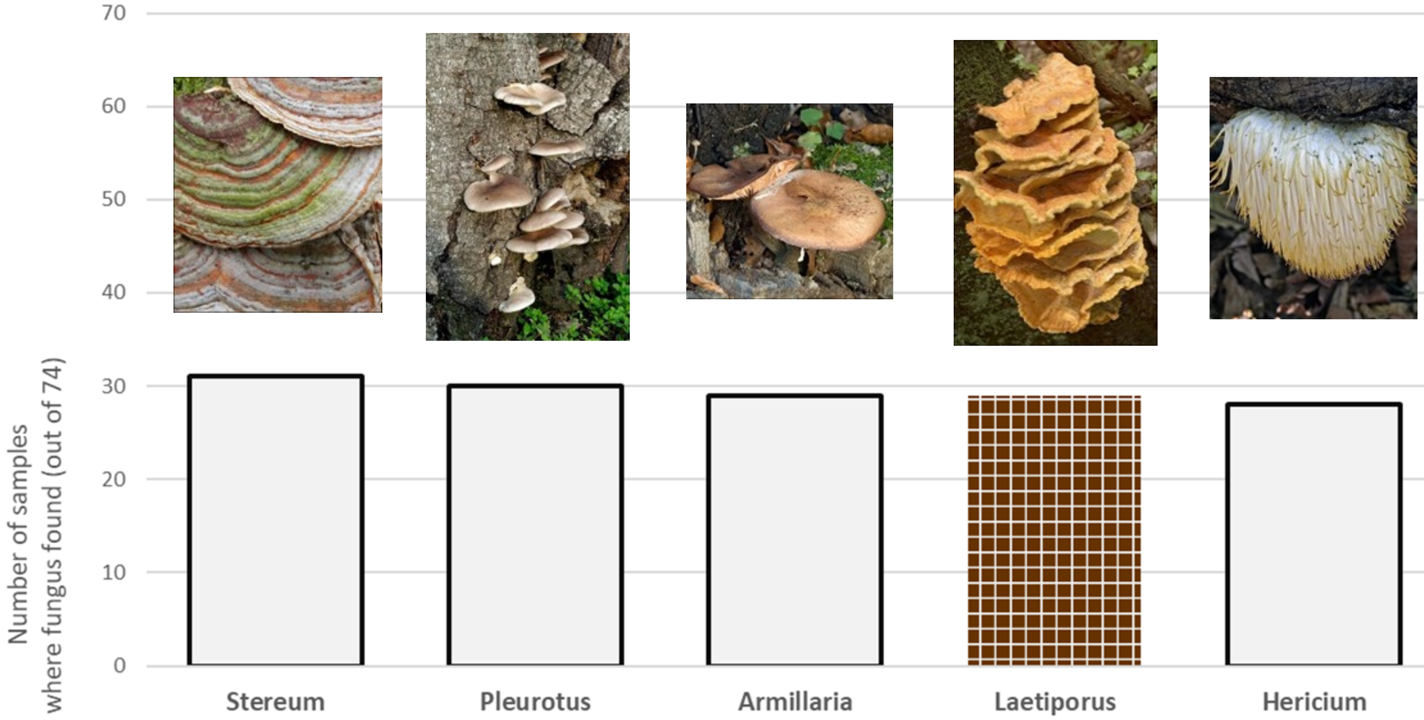
White rot (left):

The compound middle lamella is degraded (*lignin* lost) and cells separate (arrows)



Brown rot (right):

secondary walls (*cellulose*) are degraded first (holes), but the middle lamella remains intact longer



	Stereum	Pleurotus	Armillaria	Laetiporus	Hericium
Type	White rot	White rot	White rot	Brown rot	White rot
Pathogenicity	Secondary	Secondary	Primary	Primary	?
Location	Saprot	Heartrot	Canker rot, heartrot	Heartrot	Heartrot

Notes	Thought to be mostly a saprobe	Edible! ("oyster mushroom)	Both a pathogen and a saprophyte	May be a sign of extensive decay	Associated with wounds or cavities

Fungal photos: Dr. Amadej Trnkoczy, and Dr. Nick V. Kurzenko (all from CalPhotos)

Andrew L. Loyd

Ph.D Candidate

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Elucidating "lucidum": Distinguishing the Many Faces of *'G. lucidum'* in the United States

Ganoderma is a large and diverse, globally-distributed genus of basidiomycete wood decay fungi that includes species that cause white rot on a variety of tree species. The taxonomy of the laccate (shiny or varnished) *Ganoderma* species is confusing, but we are elucidating evolutionary relationships among taxa via molecular phylogenetic studies.

For the past century, many studies of *Ganoderma* have used the name *G. lucidum* for any laccate *Ganoderma* species growing on hardwood trees. Molecular studies have established that *G. lucidum sensu stricto* (Curtis) Karst is not native to North America. Our surveys of over 500 collections of *Ganoderma* species collected in the United States have revealed 12 putative native taxa, including: *G. curtisii* (Berk.) Murrill, *G. martinicense* Welti & Court., *G. meredithiae* Adask. & Gilb., *G. oregonense* Murrill, *G. polychromum* Murrill, *G. ravenelii* Steyaert, *G. sessile* Murrill, *G. tsugae* Murrill, *G. tuberculosum* Murrill, *G.* c.f. *weberianum* (Bres. & Henn.) Steyaert, *G. zonatum* Murrill, and *Tomophagus colossus* (Fr.) Murrill (syn. *G. colossus*).

Many of these taxa infect trees and cause root and butt rot, but the pathogenicity and decay ability within the genus is understudied. Some, such as *G. zonatum* are aggressive pathogens, and have been associated with tree failure and mortality of mature palms, while others, are often saprophytic causing decay in old, weakened tress and can potentially be latent opportunistic saprophytes. *Ganoderma* species identification tools are needed to assist arborists with predicting tree failure when fruiting bodies of *Ganoderma* are present. Biological differences likely exist among the native North American *Ganoderma* species, and these results will be presented.

A B C D E

The Laccate *Ganoderma* of the Southeastern United States: A Cosmopolitan and Important Genus of Wood Decay Fungi[1]

Andrew L. Loyd, Jason A. Smith, Brantlee S. Richter, Robert A. Blanchette, and Matthew E, Smith[2]

Summary

Ganoderma Karst. is a large and diverse genus of wood decay fungi that can rot the roots and/or lower trunk of many tree species. There are several laccate (varnished or polished) *Ganoderma* species that are found in the southeastern United States. These species can be recognized by their shiny, reddish-brown, and shelf-like fruiting bodies. These fruiting bodies have a pale pore surface on the bottom that darkens with age or handling and can be stipitate (stem present) or sessile (stem absent). Laccate *Ganoderma* species fruit year-round in most parts of the southeastern United States, but fruiting may be restricted to warm months in northern areas. When *Ganoderma* fruiting bodies are observed, it is an indication that wood decay is active, whether on fallen logs, buried roots, or the trunks of living or dead trees.

Introduction

Ganoderma species are white rot fungi, which means they can break down both cellulose and lignin, the structural components of wood (Sinclair and Lyon 2005). *Ganoderma* species are generally associated with the decay of roots and/or the lower trunk and root flare, which can lead to hazardous tree conditions and tree failures, resulting in serious damage to property and life.

Fruiting bodies of *Ganoderma* are often found in association with declining trees, especially in urban landscapes. However, they can also be found at the base of affected living trees where there are localized pockets of decay within the tree, on dead trees, or associated with buried infected wood or roots of previously removed trees. The presence of *Ganoderma* fruiting bodies on living trees does not always indicate imminent tree failure or death, and some *Ganoderma* species are more aggressive pathogens than others. For example, *G. zonatum* Murrill has been documented as a serious pathogen of palm trees and can contribute to tree mortality and failure by windthrow (Elliott and Broschat 2001) (Figure 1A). Other species, such as *G. sessile* Murrill and *G. curtisii* (Berk.) Murrill, seem to be opportunistic pathogens and typically only cause serious decay in old or stressed trees (Sinclair and Lyon 2005). Some tree species, such as *Quercus virginiana* (southern live oak), can resist decay because they produce dense wood with antimicrobial chemicals and they compartmentalize infections. In contrast, species such as *Quercus hemisphaerica* ("laurel" or Darlington oak) are less efficient at combating fungal infections and are therefore more susceptible to decay.

Knowledge of which *Ganoderma* species is present and what tree species is infected can assist with tree structure evaluations and risk assessments of hazardous trees.

Taxonomy

The taxonomy (classification) of North American *Ganoderma* species is quite confusing and has been in a state of flux for the past 20 years. However, with the advancement of molecular genetic investigations, the species complex is being elucidated (Cao et al. 2012; Moncalvo et al. 1995; Zhou et al. 2015). In the past century, many authors that have reported findings of *Ganoderma* in the United States have used the name *'G. lucidum'* for any laccate *Ganoderma* species growing on hardwood trees (Adaskaveg and Gilbertson 1988, of fungi are commonly referred to as “reishi” or “Ling-zhi” (Hennicke et al. 2016). It is now recognized that cultivated “reishi or “Ling-zhi” in

Asia actually represents several species, such as *G. lingzhi* Sheng H. Wu, Y. Cao & Y.C. Dai, *G. sichuanense* J.D. Zhao & X.Q. Zhang, and *G. multipileum* Ding Hou (Cao et al. 2012).

Laccate *Ganoderma* Species of the Southeastern United States

There are approximately ten laccate *Ganoderma* species that have been reported in the southeastern United States (Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee). These are *G. curtisii, G. martinicense* Welti & Court., *G. meredithiae* Adask. & Gilb.*, G. ravenelii* Stayaert*, G. sessile, G. tsugae* Murrill*,*
G. tuberculosum Murrill*, G. weberianum* (Bres. & Henn.)
Steyaert, *G. zonatum,* and *Tomophagus colossus* (Fr.) Murrill (formerly known as *G. colossum* (Fr.) Baker). The most commonly observed species in the southeastern
United States are *G. curtisii* and *G. sessile*, but in Florida *G. zonatum* is also commonly found, specifically on palm trees (Figure 1).

The morphology of basidiocarps (conks) of the laccate *Ganoderma* species can be highly variable, which presents challenges for species level identification. For example, species such as *G. curtisii* and *G. meredithiae* are practically identical in the field. However, the former is typically found in association with hardwood trees (especially oaks), while the latter is associated with pines. Some species are generalists and can be found in association with a diverse range of host trees, and other species are specialists. For example, *G. sessile* is a generalist that can be commonly found on many species, such as oaks, maples, redbuds, and other deciduous trees, whereas *Ganoderma zonatum* is a specialist that can only be found on palms.
Generally, all laccate *Ganoderma* species have woody to spongy fruiting bodies that grow on the lower portions of trees (i.e. lower trunk, root flare, roots, etc.). The characteristics that are most helpful for species identification are the color of the fruiting body, whether it has stipitate or sessile anatomy (presence or absence of a stalk), context tissue characters (tissues between cap crust and tubes and throughout the stem, Figure 3A), and host tree species. Fruiting bodies range in color from yellow to brown to reddish-brown and are mostly “shiny” on non-spore producing surfaces. Stipes (stalks) can be present or absent (sessile) and when present can range from short, stocky stalks that are referred to as pseudostipes to lengths that are equal to or greater than the diameter of the cap (Figure 2). The context tissue ranges from white or cream to dark brown in color and corky to felty in texture. Black, often shiny, resinous deposits throughout the length of the stipe and/or concentric zones in the context tissue are features that are important characteristics for some species (Figure A rudimentary key to the southeastern US laccate *Ganoderma* species is provided below.)

Microscopically, spore size and shape can distinguish some species, but in most species the spores are quite similar. All *Ganoderma* species have bitunicate (double-walled) basidiospores that are pigmented, appearing golden-brown (Figure 4A). The inner wall is pigmented and extends through the hyaline (not pigmented) outer wall as small pillars, making the spores appear subtly echinulate (spiny) under the light microscope (Figure 4A). Some species have spores that appear “rough,” while others have spores that appear “smooth.” The distinction between “rough” and “smooth” spores can be subjective and is only a relative distinction among the species, resulting from differences in the thickness and abundance of pillars from the inner spore wall (Steyaert 1980) (Figure 4). Lastly, there are species of *Ganoderma* that produce chlamydospores in the fruiting body or in culture. Chlamydospores are thick-walled asexual spores that function as survival structures, which can persist in extreme temperatures and drying conditions. These structures are variable within the genus *Ganoderma* and can be hyaline to pigmented, round to obovate, and smooth or ornamented, depending on the species (Figure 4).

Basic Key to the Laccate
Ganoderma spp. of the Southeastern United States

Disclaimer: This key is rudimentary and is mostly based on macromorphology, geography, and host. This is not to be final and is based on species designations present in the literature at the date of this publication. The designations are subject to change as more investigations are made (Figure 5).

Typically stipitate fruiting body with a true stipe (commonly laterally produced).. 2

1.Sessile fruiting body, or if a stipe is present, less than half the length of the cap diameter....................................... 4

Cream or buff context tissue with no black, shiny, resinous deposits.. *G. ravenelii*

Cream or buff context with black, shiny resinous deposits present... 3

Found predominately on hardwoods, especially oaks, growing from roots... *G. curtisii*
Found predominately on pines with a distribution in the Gulf South.. *G. meredithiae*
Fruiting body yellow, spongy (not woody), large basidiospores (13–18 x 9–12µ)…………… *Tomophagus colossus*

Not as above……………..… 5

Context tissue dark brown.. 6

Context tissue white to cream to light brown............. 8

Found predominately on palms, slender basidiospores (length/width ≈ 2).. *G. zonatum*
Not as above... 7

7. Mostly sessile, limited to South Florida, squatty basidio spores (length/width ≈ 1.3-1.5) ……...G. tuberculosum-

Typically centrally pseudostipitate with resinous bands present in the context tissue................. *G. martinicense*

Context tissue nearly pure white, in temperate locales, mainly on *Tsuga* spp... *G. tsugae*

Not as above... 9

Pigmented chlamydospores in context tissue, limited to south Florida.. *G. weberianum*

9. No pigmented chlamydospores in context tissue, found in all states east of the Rockies........................... *G. sessile*

Management

With the exception of *G. zonatum,* a pathogenic species affecting virtually all palm species in the United States, *Ganoderma* species in the southeastern United States are mostly opportunistic pathogens that take advantage of stressed plants. Information on management for *G. zonatum* can be found in *Ganoderma Butt Rot of Palms*, http://edis.ifas.ufl.edu/pp100 (Elliott and Broschat 2000). Drought-stressed plants and plants growing under suboptimal conditions in urban settings appear to be more susceptible to decay by *Ganoderma.* Choosing the appropriate tree species that meets the expectations of maintenance inputs for a given landscape can be an effective management strategy to prevent and/or slow decay. For example, in low maintenance landscapes, such as median plantings along roadsides, utilizing relatively drought-tolerant plants can reduce the chances of pest problems such as decay fungi. Planting tree species that are chemically and physiologically tolerant to decay is another effective management tactic to avoid potential infections. Specific trees have different relative tolerance to fungal decay because of their chemical, morphological, and physiological characteristics (Scheffer and Cowling 1966; Scheffer and Morrell 1998). For example, black walnut and black locust are generally more tolerant to decay than cottonwoods and birches (Scheffer and Morrell 1998). Maintaining healthy trees by preventing wounding and providing proper fertilization, irrigation, mulching, and other plant health care tactics will improve the resiliency and resistance of trees to decay fungi.

When *Ganoderma* fruiting bodies are found in the landscape, a tree risk assessment, as outlined by the ISA Best Management Practice, should be performed to evaluate the level of hazard presented (Dunster et al. 2014). Fruiting bodies of *Ganoderma* can be found in trees with localized pockets of decay as well as trees that have extensive decay. Structure evaluations as basic as “sounding” the tree with a mallet or using a probe can estimate the extent of decay in a particular part of a tree. More advanced methods, such as using sonic and electrical resistance tomography, can also be used to quantify the area of decay within trees, relative to healthy wood. These types of approaches may help with management decisions, such as when to remove a tree because decay is extensive and the tree hazardous (Elliott et al. 2016).

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Figure 1. Common laccate *Ganoderma* species of the southeastern United States. A) Canopy collapse symptom of *Butia odorata* (Jelly palm) infected with *Ganoderma zonatum*; B) *Ganoderma zonatum* fruiting on a trunk of *B. odorata*; C) *Ganoderma curtisii* fruiting bodies on a root flare of a *Quercus* sp. (oak); D) *Ganoderma sessile* fruiting bodies on a trunk of a *Salix* sp. (willow); E) *Ganoderma tsugae* fruiting on *Tsuga canadensis* (hemlock) trunk.
Credits: A) Andrew Loyd, UF/IFAS; B) Andrew Loyd, UF/IFAS; C) Andrew Loyd, UF/IFAS; D) Matt Losey, Bartlett Tree Experts; E) Robert Blanchette, University of Minnesota, Department of Plant Pathology

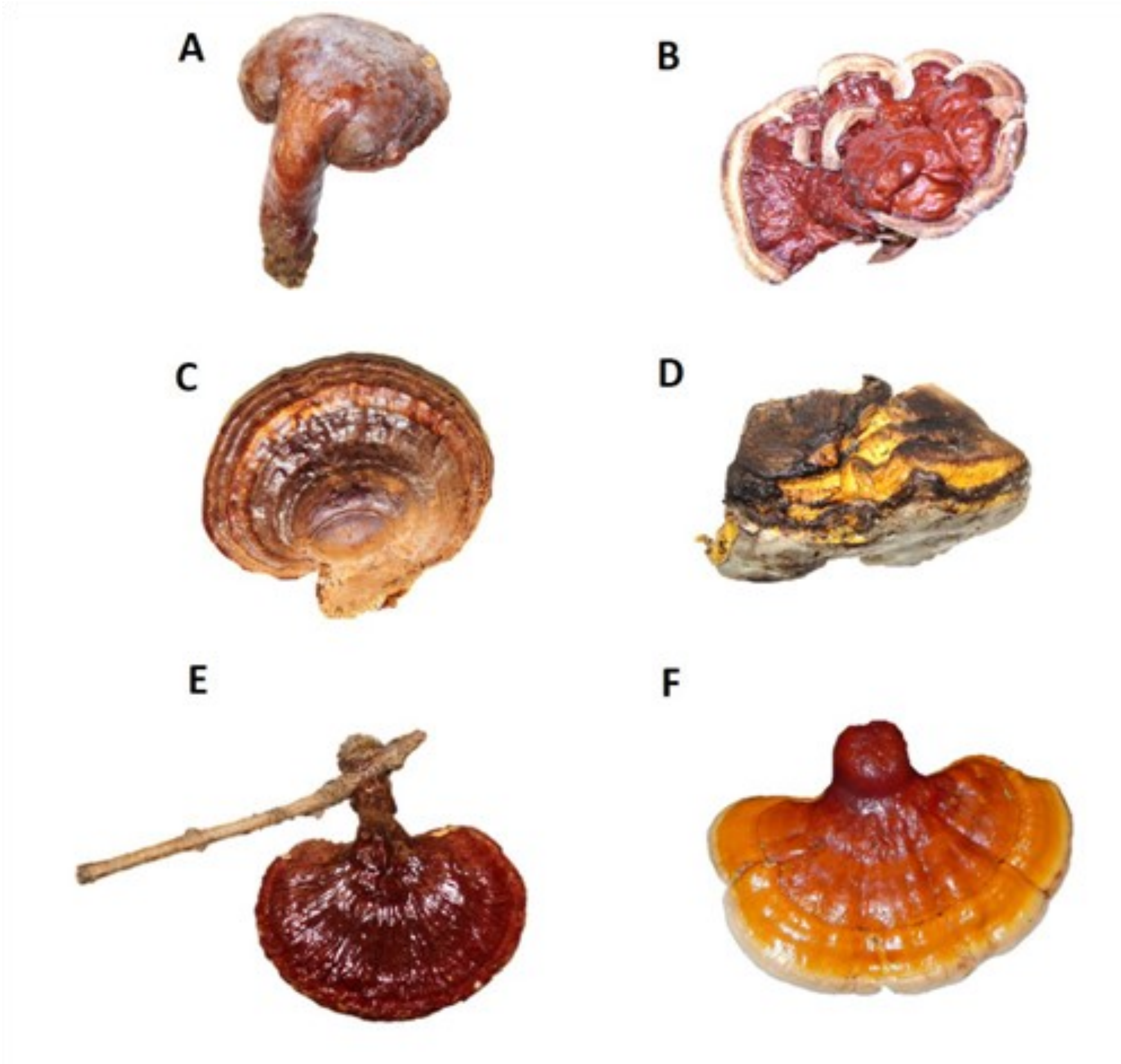

Figure 2. Range of different macromorphological characters of laccate *Ganoderma* spp. A) Reddish-brown with subtle purple hues of a stipitate form of a typical *G. curtisii*; B) Highly varnished, red sessile fruiting body typical of *G. sessile*; C) Reddish-brown, sessile form of *G. zonatum* with conspicuous concentric zones typical of this species; D) Yellow, spongy fruiting body typical of *Tomophagus colossus* (syn. *G. colossus*); E) pseudostipitate (short stocky stipe (stalk)) form of *G. sessile;* F) Latterally pseudostipitate, reddish-orange fruiting body with a white margin typical of an actively growing *G. tsugae* fruiting body.

Credits: A) through E) Andrew Loyd, UF/IFAS; F) Robert Blanchette, University of Minnesota, Department of Plant Pathology

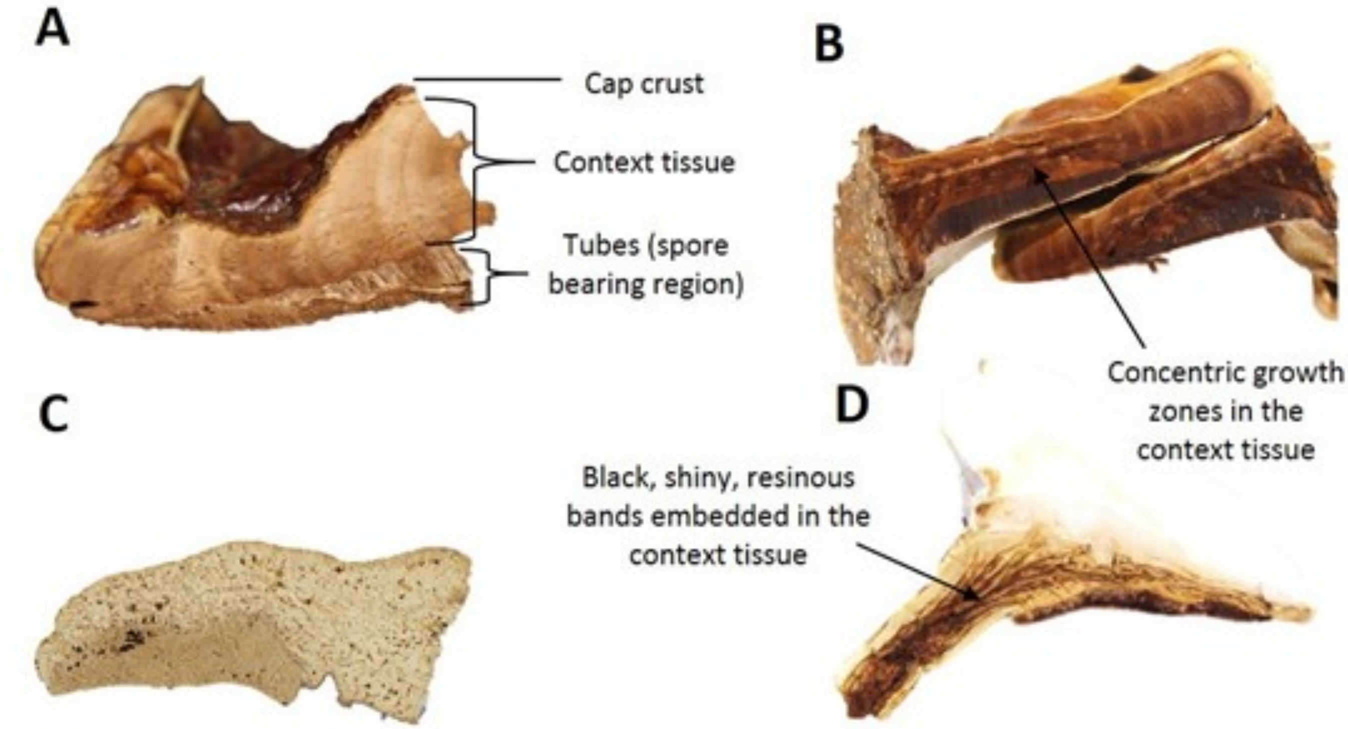

Figure 3. Range of context tissue characters of the laccate *Ganoderma* spp. A) Cream-colored context tissue with concentric growth zones typical of *G. sessile*, illustrating the location of specific basidiocarp tissues; B) Dark brown colored context tissue with concentric growth zones (arrow) of *G. tuberculosum*; C) All white, homogenous context tissue of *G. tsugae*; D) Cream-colored context tissue with black, shiny resinous bands (arrow) typical of *G. curtisii*.
Credits: Andrew Loyd, UF/IFAS

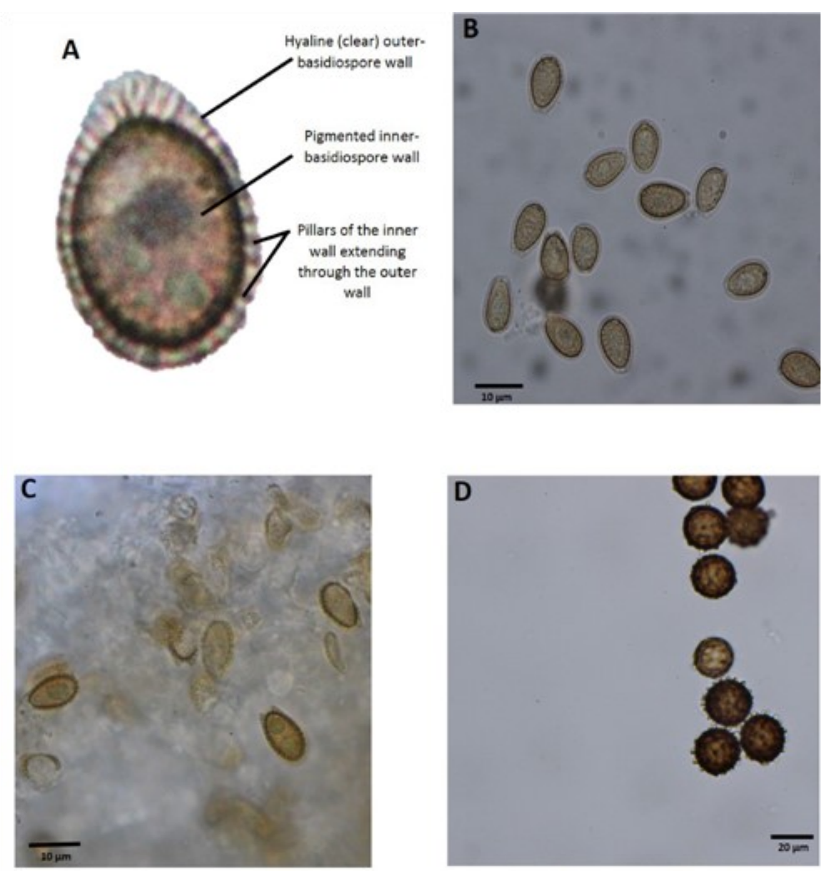

Figure 4. Basidiospore and chlamydospore morphology. A) Typical morphology of basidiospores of *Ganoderma* species, depicting the hyaline (non-pigmented) outer wall and pigmented inner wall that protrudes through the outer wall as small pillars; B) "Smooth" basidiospores of *G. sessile,* which appear smooth due to thin pillars of the inner spore wall; C) "Rough" basidiospores of *G. curtisii,* which appear rough due to thicker pillars of the inner spore wall; D) Pigmented, highly-ornamented, chlamydospores of *T. colossus*, which can be found consistently throughout the context tissue of the fruiting body. Credits: Andrew Loyd, UF/IFAS

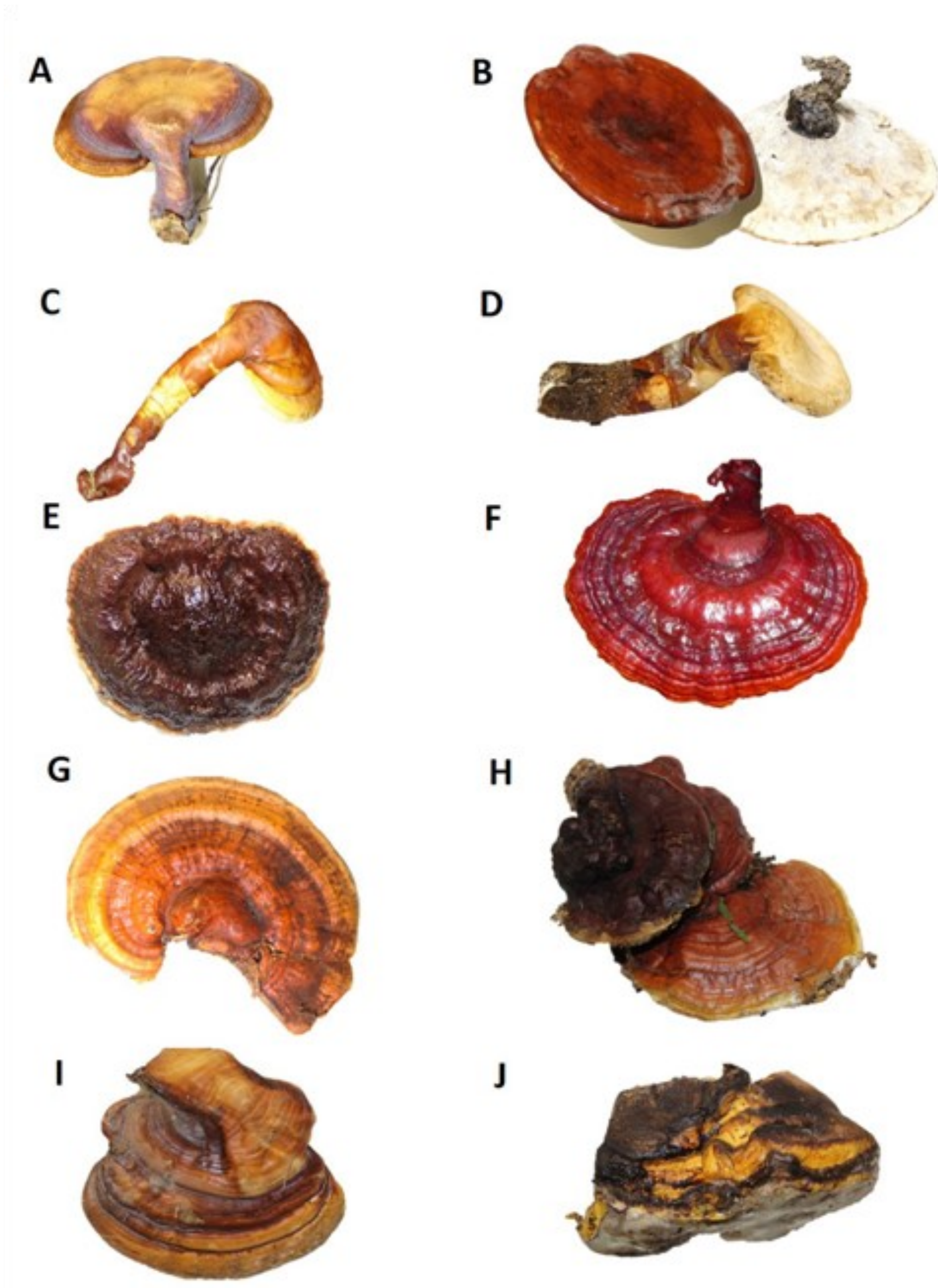

Figure 5. Representative fruiting bodies of Ganoderma species from the southeastern United States. Disclaimer: morphology of fruiting bodies can be highly variable within a species due to age, environment, and location. (A-J) These represent fruiting bodies of typical form from collections within the southeastern United States: A) *G. curtisii*, B) *G. martinicense* (top and bottom view), C) *G. meredithiae*,
D) *G. ravenelii*, E) *G. sessile*, F) *G. tsugae*, G) *G. tuberculosum*, H) *G. weberianum*, I) *G. zonatum*, and J) *Tomophagus colossus*. Credits: A) through E) Andrew Loyd, U F/IFAS; F) Robert Blanchette,
University of Minnesota, Department of Plant Pathology; G) through J) Andrew Loyd, UF/IFAS

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Laurel wilt: an Emerging Threat to the Lauraceae in the United States

Laurel wilt, a disease caused by the fungus *Raffaelea lauricola*, was first reported in Georgia in 2002. Since its introduction, this disease has caused the death of nearly 500 million trees throughout the southeastern U.S.

This disease affects members of the Lauraceae family, which includes species such as *Persea borbonia* (redbay) and *Persea americana* (avocado). Surveys of *R. lauricola* isolates and its vector, the redbay ambrosia beetle (*Xyleborus glabratus*), from the southeastern U.S. have shown that this pathogen and its vector are propagating clonally, which suggests that this epidemic could have been the result of a single introduction.

The beetle and fungus were most likely introduced from Taiwan, where there are genetically distinct populations of *R. lauricola*. Furthermore, the pathogenicity of *R. lauricola* on hosts in its native range is unknown, but has been found to cause disease on domesticated *Persea americana*. The redbay ambrosia beetle behaves atypical of other native ambrosia beetles in the U.S. in that it infests live, healthy trees, specifically in the family Lauraceae.

Wilt occurs in trees, putatively, by an overreaction in the host to the presence of the fungus, which triggers the production of tyloses in the xylem vessels, ultimately disrupting the movement of water throughout the plant. In addition to the introduced vector (*X. glabratus*) additional, native beetles to the U.S. have been found to carry *R. lauricola* into trees. Furthermore, although laurel wilt has been devastating to Lauraceae members (redbay, avocado, sassafrass, etc.) only in the current range of the beetle and fungus since the introduction, recent artificial inoculation studies have shown that *Umbellularia california* (California bay laurel), an endemic tree species to coastal California and southern Oregon, is a susceptible host.

If the redbay ambrosia beetle and its fungal symbiont (*R. lauricola*) make it to California it could seriously threaten this ecologically important understory tree. This presentation will focus on biological invasions using the laurel wilt pathosystem as a case study highlighting the research efforts to better understand and manage this devastating disease.

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Tree Disease and Wood Decay as Agents of Environmental and Social Change

Wood Decay All Around Us

The breakdown or decay of wood is a prominent process in landscape health and disease. The bulk of the energy captured and stored by natural woodlands, orchards, and agroforestry operations is allocated to produce wood. The release of that stored energy and the cycling of the constituent mineral elements into environmental pools and other organisms is through processes of wood decay. Wood decay is an ordered process, primarily through the biology of specialized fungi and associated microorganisms and arthropods. Traditionally, plant pathologists viewed wood decay in terms of lost economic value of timber, products, and secondarily as a potential source of risk for structural failure of urban and community trees. Mycologists studied the great diversity of wood decay fungi in terms of taxonomy or natural history. More recent research has focused on the role of wood decay in the development of healthy trees and forests and biogeochemical cycling.

Although valued by some for food or craft materials, wood decay fungi are generally ignored or not even noticed by the general public. Whether escaping popular notice or not, wood decay fungi have had persistent effects on international relations, the history of science, and modern-day environmentalism and medicine, well beyond the limits of both natural history and timber production. The objective of this paper is to show a few of the linkages of wood decay to larger processes of politics, philosophy, and human society.

Wood Decay and International Power

Geopolitical history in the 16th through 19th Centuries was largely determined by resource acquisition, mercantilist advantage, and military naval actions, all dependent on wooden ships. The need for high-quality wood products both to maintain those forces and to support commerce provided an additional impetus for exploration and colonization.

As detailed by Ainsworth (1976), the attempted invasion of England by the Spanish Armada provides an example of the role of wood decay in European affairs with global implications. As part of the ongoing struggle for European dominance and control of New World resources in the 16th Century, Spain assembled a naval force for the invasion of Britain. British raids on the Spanish coast in 1587, a year before the Armada was launched, damaged some Spanish ships prior to deployment. As importantly, the raids destroyed many of the seasoned barrels intended for use to store food and water for the Armada. The pressing need for replacements was met by new construction, much of which was based on the use of green sapwood, rather than from properly dried heartwood. The low resistance to decay in the new barrels resulted in extensive food spoilage and water contamination prior to Spanish forces reaching the English coast. Structural failure of wooden planks and structural members contributed to ship losses before engagement of the Spanish and English fleets. Although multiple factors were surely in play, the defeat of Spanish forces enhanced the opportunity for England to become a major naval power and an expansionist global force. Part of the expansion was stimulated by the need to acquire from the New World and tropical Asia the timber of appropriate size and decay resistance to support the growing British navy and the commerce of the ever-expanding commercial fleet.

The British navy was not exempt from the hazards of wood decay. Extensive fruiting of wood decay fungi in ship holds and planking of newly commissioned ships was noted in official reports in the 1680s. This was attributed to the lack of availability of oak heartwood, it having mostly been cut from the British Isles over the preceding decades. The introduction of copper plating in ships of the Napoleonic era in the early 19th century helped to protect the exterior of ship hulls from shipworms (boring mollusks), but the interior planking and fittings continued to contain extensive decay and to be unusable even at the time of launching or shortly thereafter.

Wood Decay and the Germ Theory

Well into the 19th Century, mushrooms and other fungi were believed to arise spontaneously from the interaction of soil or dead plant material with the physical environment. With some notable exceptions, scholars continued to interpret the growth of fungi along the conceptual lines of the ancient Greeks, most fully developed by Aristotle. In this view, though life could be maintained from generation to generation through seed production, life was also possible through spontaneously generation under the proper combination of the fundamental four elements of earth, air, fire, and water plus the *pneuma*, the latter conceived as the vital breath or heat.

From a purely observational perspective, spontaneous generation appealed to common sense. Although early microscopists noted mushroom spores in the 17th Century, the mushrooms that sprout from the compost pile did not apparently require seeds. The exposure of dead plant matter to wind, rain, and soil is often associated with the heat of fermentation which can be seen rising from compost piles. The development of thin hyphal threads ramifying within organic matter and the eventual fruiting of mushrooms were all consistent with Aristotle's biology. To move beyond the dominance of Aristotle and to understand wood decay requires a side trip into the pathology of field crops.

The late blight of potato caused by *Phytopthora infestans*, the preeminent agricultural disease of 19th Century Europe, was believed to be related to some adverse combination of rainfall and "bad air", possibly mediated by lightning or through some supernatural agency (Matta 2010). Clearly, the disease was worsened under wet conditions. The fungus associated with necrotic foliage was described and named (as *Botrytis infestans* and later *Peronospora infestans*) in 1845, at the height of the outbreak associated with the Irish Potato Famine.

The prevailing view was that the fungal growth was an excretion or malformation of the plant analogous to a suppurating rash in animals. Growth of the fungus was interpreted as due to inherent defects in the plant, improper cultivation practices, and the environmental conditions. The critical point to this discussion is that the fungus was seen as the *result* of the disease. Field inoculation and laboratory experiments by Heinrich Anton de Bary completed in 1853 established that the fungus *caused* the potato blight. De Bary's research involved a critically important crop and was well recognized by the scientific community. The research on the microbial involvement in the fermentation process by Louis Pasteur published in the late 1850s and 1860s reached a broader industrial and general audience. Although they did not invent the concept of the germ theory, the research by de Bary and Pasteur in the 1850s and 1860s effectively discredited spontaneous generation, although the concept persisted in some quarters, including forestry.

The scientific transition is clear in descriptions of wood decay by the father and son researchers Theodor and Robert Hartig (1805-80 and 1839-1901, respectively). A pioneering anatomist of the microscopic structure of wood as well as a forest entomologist, T. Hartig described fungal hyphae in decaying wood in 1833. He and subsequent researchers interpreted that the hyphae were the *result* of wood decomposition by simple abiotic weathering, consistent with the concept of spontaneous generation. That interpretation was reversed by R. Hartig's description of the hyphae as the *cause* of the decayed wood (Merrill, Lambert, and Liese 1975).

The younger Hartig presented foresters and forest scientists a new paradigm, that wood decay was the result of infection by fungi. These fungi had identifiable life cycles and that once initiated, disease progressed according to understandable patterns.

Medical Uses of Wood Decay Fungi

In the US, wood decay fungi already in use abroad are being assessed for safety and effectiveness (Gargano and others 2017). A few of the most familiar wood decay fungi currently being tested are listed below. Inclusion in the list is not an endorsement of therapeutic value but is simply an indication of how commonly encountered wood decay fungi are being investigated for medicinal properties.

The common turkey tail fungus (*Trametes versicolor*, syn. *Coriolus versicolor*) occurs frequently on recently wounded sapwood or freshly cut stumps and timber in North America. Although most frequently on broadleaved trees, *T. versicolor* occasionally occurs on conifers as well. *Trametes versicolor* produces peptide-linked polysaccharides (short chains of sugar molecules linked to a small protein) as an adjuvant with traditional chemotherapy to reduce rates of tumor growth and to reduce side effects of chemical treatment.

Another wound pathogen of broadleaved trees is the split gill fungus (*Schizophyllum commune*). Although not commonly valued as an edible mushroom in North America, *S. commune* is cultivated as a food item in the south Asian tropics where it is cultivated. Extracts of *S. commune* are broadly anti-microbial and inhibit reverse transcriptase, an important enzyme for virus replication. In addition to potential medical benefits, the white rot decay system that the fungus uses can also breakdown and detoxify some serious pollutants. In part due to the ability to be cultured on a large scale, *S. commune* is one of several fungi in pilot tests to bioremediate landscapes polluted by releases of toxic organic chemicals.

Restricted to trees in the genus *Betula*, the birch polypore (*Fomitopsis betulina* syn. *Piptoporus botulinum*, *Polyporus betulinus*) is distributed across the northern hemisphere, wherever birch is found. Current folk practices include the use of *F. betulina* for immune system support, control of internal parasites such as the *Trichuris* nematode, and as a styptic material. The birch polypore received special attention after the discovery of the Tyrolean Man, nick-named Ötzi, a naturally-formed mummy dated to have died in about 3300 BCE (Peinter and Poder 2000, Pleszczyńska and others 2017). Uncovered by a melting glacier along the alpine border of Austria and Italy, the presence and possessions of Ötzi stimulated research in European culture and technology of the Copper Age and wonder at his journey across inhospitable terrain. Among his posessions, Ötzi carried two wood decay fungi. Pieces of the fruitbody of *F. betulina* were strung on a leather thong and are believed to have been carried for medicinal purposes. Along with flints for striking sparks, Ötzi also carried amadou or tinder derived from *Fomes fomentarius*, the tinder fungus. The hard fruiting bodies of the tinder fungus are beaten to yield the soft and fluffy amadou, perfect to catch sparks and to smolder in the process of fire-starting. The amadou from *F. fomentarius* is also included in several traditional pharmacopoeias to stanch bleeding.

Pathologists and land managers need to be concerned with the effects of wood decay on the yield of goods and services. Interestingly, the effects of the fungi may be positive and beneficial as well as potentially negative and costly.

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Figure Captions

Figure 1. Are Armillaria rhizomorphs or "shoestrings" the cause or the effect of wood decay?

Figure 2. The turkey tail fungus (*Trametes versicolor)* on maple firewood converts cellulose and lignin into potentially medicinal peptide-polysaccharides.

Figure 3. The split gill fungus (*Schizophyllum commune*, left—upper surface, right—lower surface) produces antiviral compounds as well as potential use to bioremediate environmental pollution.

Figure 4. The tinder fungus (*Fomes fomentarius*) on birch, an important component of ancient technology to use fire.


Fig. 1


Fig. 2

Fig. 3

Fig. 4

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Emerging Diseases of Common California Landscape Plants

In recent years, a few notable diseases have been introduced or recognized affecting common landscape plant species in California. While these diseases are unlikely to have a dramatic impact on native plant communities or alter ecosystem function, they will be a major concern for arborists, landscapers, and nursery professionals as they affect common and widely planted ornamental tree and shrub species. Here I provide details regarding symptoms, pathogen biology (if known), and potential management options for an undescribed canker disease of *Arbutus* x 'Marina', a new foliar host of *Phytophthora ramorum* (*Lophostemon confertus*), and boxwood blight (*Calonectria pseudonaviculatum*).

Canker of *Arbutus* x 'Marina'

An undescribed pathogen, likely a fungus, is currently causing decline and mortality of *Arbutus* x 'Marina' in landscapes throughout northern and southern California, as well as Oregon, Washington, and British Columbia. *Arbutus* x 'Marina' is a hybrid species of unknown lineage that is commonly grown as a small single or multi-stemmed tree, and is increasingly found in landscapes to the point of being one of the most overplanted ornamental species in the western U.S.

The identifying symptom of this disease is the development of black or gray cankers on trunks and large limbs, most often originating at or near the soil-line, but sometimes observed higher in the canopy. Cankers have been observed on plants of a wide range of ages and size (Fig. 1 a,b). Over time, the cankers enlarge and often splits or cracks develop within the canker and progress past the margin of discoloration. Infection results in slow decline of trunks or branches distal to the canker, followed by whole-tree mortality. Significant internal discoloration of sapwood is present when dead or dying infected trees are dissected (Fig. 2).

There does not appear to be any direct link between this disease and cultural conditions. The disease has been observed in individual plants that vary widely in irrigation, planting depth, groundcover, soil fertility, soil texture, and many other environmental factors. The disease is not limited to landscape plantings, as it has also been documented in containerized plants in production facilities.

The current state of knowledge regarding this disease is limited. Samples submitted to both private and CDFA diagnostic facilities have failed to identify a definitive causal agent. Several different fungi have been identified through isolation or genetic analyses; however, no single organism has been recovered with enough consistency to proceed with formal pathogenicity testing. While the cankers appear very similar to those caused by the fungus *Neofusicoccum arbuti* on the native Madrone (*Arbutus menziesii*), *N. arbuti* has never been isolated or otherwise detected from any of the submitted samples.

Without a clear causal agent, sound management practices have not been developed. Many canker diseases of landscape plants are considered weakly pathogenic and/or secondary to abiotic physiological stress factors, however this disease has been observed on very well maintained plants as well as those subjected to obvious physiological stress. At this time the only mitigation or management strategy is to diversify landscape plantings to limit the impact if mortality of this species should occur.

New Foliar Host of *Phytophthora ramorum*

In the spring of 2017, multiple 'Brisbane Box' (*Lophostemon confertus,* formerly *Tristania conferta*) street trees in Sausalito, California developed symptoms of an unknown foliar blight disease (Fig. 3). Brisbane box is widely planted as an ornamental or street tree throughout California due to its tolerance of drought and other urban conditions including poor soil quality, ozone, and soil compaction. This species is cold hardy to about 25° F.

Symptoms of the blight included irregular leaf spotting or blotching, blackening of leaf petioles, and branch dieback with necrotic leaves remaining attached (Fig. 4). Dark, slightly sunken lesions with a water-soaked appearance developed on branches with clear transition between infected and healthy tissue (Fig. 5).

Samples were collected by the author and arborist Juan Ochoa in April 2017. It was determined through direct isolation and inspection of morphological characteristics that the causal agent was *Phytophthora ramorum*. Pathologists with the CDFA were alerted to this unreported host, and in June of 2017 CDFA personnel collected official samples and confirmed the presence of *P. ramorum*. Pathogenicity tests to prove *P. ramorum* as the causal agent are currently underway at the CDFA facility in Sacramento (S. Latham, *personal communication*). Dr. Suzanne Latham with the CDFA also noted that similar symptoms were documented on Brisbane Box growing in the Presidio area of San Francisco in 2012 but no causal agent was determined at that time.

Trials on effective management of Ramorum blight on this host have not been conducted, however sanitation pruning of infected branches several inches below the transition from live to dead tissue is recommended. In addition, application of systemic materials with the active ingredient potassium phosphite may help to improve resistance, as has been shown in other hosts. It is assumed that the exceedingly wet winter of 2016-2017 in the San Francisco Bay area contributed to the development of disease.

Boxwood Blight in California

In 2017, the pathogen responsible for causing 'boxwood blight', *Calonectria pseudonaviculatum*, was confirmed from symptomatic boxwoods in San Mateo and Santa Clara counties (S. Latham, *personal communication*). Boxwood blight is a serious disease of boxwood and some related species, and can spread rapidly and lead to rapid mortality under conducive environmental conditions.

Boxwood blight has been present in the eastern United States since at least 2011, and more recently, it was confirmed to be present in Oregon and British Columbia. The extensive use of boxwood in ornamental landscapes and the high rate of mortality following infection makes this a highly impactful landscape disease, although no state or federal quarantines are in place at this time. In eastern locations, infection usually progresses rapidly to cause plant mortality, but the epidemiology of the disease in the climates typical of California is not known.

Fig. 1 a

Fig. 1 b

Fig. 2

Fig. 3

Fig. 4

Fig. 5


Fig. 6


Fig. 7

Fig. 8


Fig. 9