Plant Health Care: Callus, Woundwood, Barrier Zones, Reaction Zones, and More

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URBAN FORESTRY LLC

Decay does not cause fungi

Robert Hartig, 1874

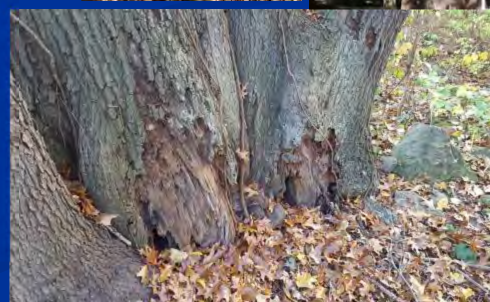
Father of Forest Pathology


TEXT-BOOK

DISEASES OF TREES

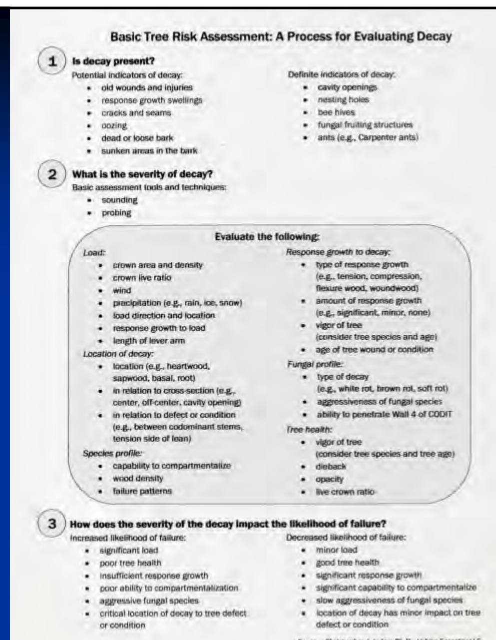
Wound Response, Decay Assessment and PHC

- Biology of tree response to wounding
- External Wound Response
  - PHC and Pest resistance
  - Decay assessment
- Internal Response
  - CODIT
  - Decay Progression, and Decay Fungi



Decay Assessment

- ANSI –Risk
- BMP Risk
- TRAQ



Basic Tree Risk Assessment: A Process for Evaluating Decay

1 Is decay present?

Potential indicators of decay:
- old wounds and injuries
- response growth swellings
- cracks and seams
- oozing
- dead or loose bark
- sunken areas in the bark

Definite indicators of decay:
- cavity openings
- nesting holes
- bee hives
- fungal fruiting structures
- ants (e.g., Carpenter ants)

2 What is the severity of decay?

Basic assessment tools and techniques:
- sounding
- probing

Evaluate the following:

Load:
- crown area and density
- crown live ratio
- wind
- precipitation (e.g., rain, ice, snow)
- load direction and location
- response growth to load
- length of lever arm

Location of decay:
- location (e.g., heartwood, sapwood, basal, root)
- in relation to cross-section (e.g., center, off-center, cavity opening)
- in relation to defect or condition (e.g., between codominant stems, tension side of lean)

Species profile:
- capability to compartmentalize
- wood density
- failure patterns

Response growth to decay:
- type of response growth (e.g., tension, compression, flexure wood, woundwood)
- amount of response growth (e.g., significant, minor, none)
- vigor of tree (consider tree species and age)
- age of tree wound or condition

Fungal profile:
- type of decay (e.g., white rot, brown rot, soft rot)
- aggressiveness of fungal species
- ability to penetrate Wall 4 of CODIT

Tree health:
- vigor of tree (consider tree species and tree age)
- dieback
- opacity
- live crown ratio

3 How does the severity of the decay impact the likelihood of failure?

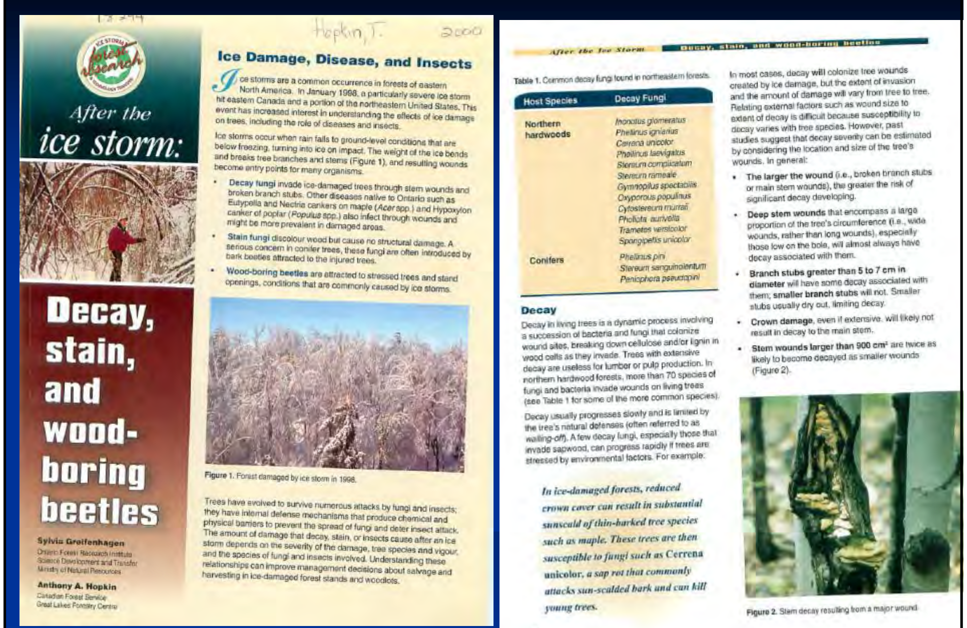
Increased likelihood of failure:
- significant load
- poor tree health
- insufficient response growth
- poor ability to compartmentalization
- aggressive fungal species
- critical location of decay to tree defect or condition

Decreased likelihood of failure:
- minor load
- good tree health
- significant response growth
- significant capability to compartmentalize
- slow aggressiveness of fungal species
- location of decay has minor impact on tree defect or condition

Source: Christopher J. Luley, Ph.D., Urban Forestry LLC

Wounds Depth, Size + Type Matter

- Most decay fungi infect through wounds
- *Depth-Expose heartwood*
- Width- Wide wounds more important than long wounds
- Size- Kills sapwood
  - 11 inch (900 cm) Circle
  - 2X more likely to become infected than smaller wounds
- *Type*
  - Most "Heart rot" fungi infect through branch or root "wounds"
    - Greater than 2 inches



Hopkin, T. 2000

After the ice storm:

Decay, stain, and wood-boring beetles

Sylvia Greifenhagen
Ontario Forest Research Institute
Science Development and Transfer
Ministry of Natural Resources

Anthony A. Hopkin
Canadian Forest Service
Great Lakes Forestry Centre

Ice Damage, Disease, and Insects

Ice storms are a common occurrence in forests of eastern North America. In January 1998, a particularly severe ice storm hit eastern Canada and a portion of the northeastern United States. This event has increased interest in understanding the effects of ice damage on trees, including the role of diseases and insects.

Ice storms occur when rain falls to ground-level conditions that are below freezing, turning into ice on impact. The weight of the ice bends and breaks tree branches and stems (Figure 1), and resulting wounds become entry points for many organisms.

- **Decay fungi** invade ice-damaged trees through stem wounds and broken branch stubs. Other diseases native to Ontario such as Eutypella and Nectria cankers on maple (*Acer* spp.) and Hypoxylon canker of poplar (*Populus* spp.) also infect through wounds and might be more prevalent in damaged areas.
- **Stain fungi** discolour wood but cause no structural damage. A serious concern in conifer trees, these fungi are often introduced by bark beetles attracted to the injured trees.
- **Wood-boring beetles** are attracted to stressed trees and stand openings, conditions that are commonly caused by ice storms.

Figure 1. Forest damaged by ice storm in 1998.

Trees have evolved to survive numerous attacks by fungi and insects; they have internal defense mechanisms that produce chemical and physical barriers to prevent the spread of fungi and deter insect attack. The amount of damage that decay, stain, or insects cause after an ice storm depends on the severity of the damage, tree species and vigour, and the species of fungi and insects involved. Understanding these relationships can improve management decisions about salvage and harvesting in ice-damaged forest stands and woodlots.

After the Ice Storm — Decay, stain, and wood-boring beetles

Table 1. Common decay fungi found in northeastern forests.

Host Species	Decay Fungi
Northern hardwoods	*Inonotus glomeratus* *Phellinus igniarius* *Cerrena unicolor* *Phellinus laevigatus* *Stereum complicatum* *Stereum rameale* *Gymnopilus spectabilis* *Oxyporous populinus* *Cytostereum murrai* *Pholiota aurivella* *Trametes versicolor* *Spongipellis unicolor*
Conifers	*Phellinus pini* *Stereum sanguinolentum* *Peniophora pseudopini*

Decay

Decay in living trees is a dynamic process involving a succession of bacteria and fungi that colonize wound sites, breaking down cellulose and/or lignin in wood cells as they invade. Trees with extensive decay are useless for lumber or pulp production. In northern hardwood forests, more than 70 species of fungi and bacteria invade wounds on living trees (see Table 1 for some of the more common species).

Decay usually progresses slowly and is limited by the tree's natural defenses (often referred to as *walling-off*). A few decay fungi, especially those that invade sapwood, can progress rapidly if trees are stressed by environmental factors. For example:

In ice-damaged forests, reduced crown cover can result in substantial sunscald of thin-barked tree species such as maple. These trees are then susceptible to fungi such as Cerrena unicolor, *a sap rot that commonly attacks sun-scalded bark and can kill young trees.*

In most cases, decay will colonize tree wounds created by ice damage, but the extent of invasion and the amount of damage will vary from tree to tree. Relating external factors such as wound size to extent of decay is difficult because susceptibility to decay varies with tree species. However, past studies suggest that decay severity can be estimated by considering the location and size of the tree's wounds. In general:

- **The larger the wound** (i.e., broken branch stubs or main stem wounds), the greater the risk of significant decay developing.
- **Deep stem wounds** that encompass a large proportion of the tree's circumference (i.e., wide wounds, rather than long wounds), especially those low on the bole, will almost always have decay associated with them.
- **Branch stubs greater than 5 to 7 cm in diameter** will have some decay associated with them; **smaller branch stubs** will not. Smaller stubs usually dry out, limiting decay.
- **Crown damage**, even if extensive, will likely not result in decay to the main stem.
- **Stem wounds larger than 900 cm²** are twice as likely to become decayed as smaller wounds (Figure 2).

Figure 2. Stem decay resulting from a major wound.

2

Wound Type

- Schwarze and Heuser (2006) showed that “shallow” sapwood wounds are relatively unimportant in “heartwood” decay infection
- More important in wound parasite infection
  - Sapwood type decay

Wounds that expose heartwood are more likely to heart rot type decay

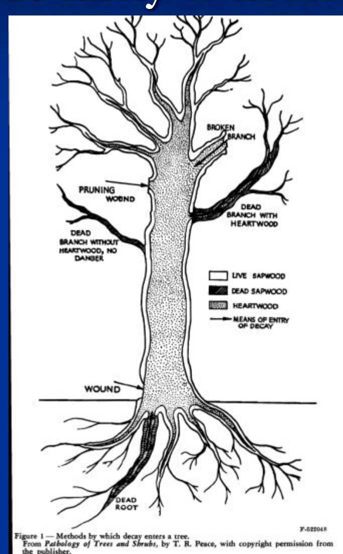


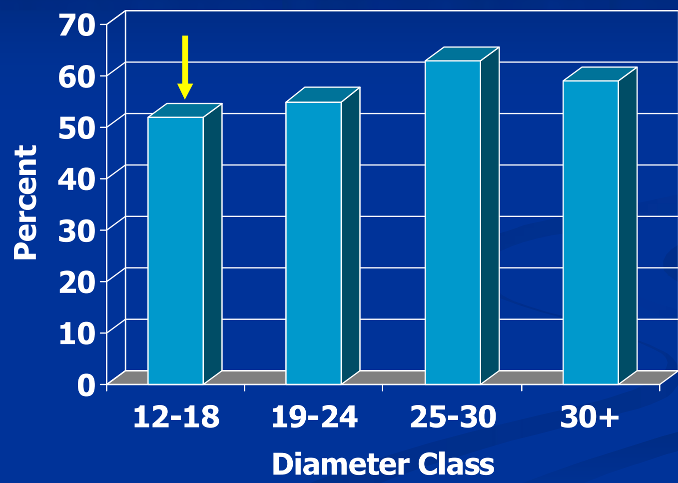
Figure 1 — Methods by which decay enters a tree.
From *Pathology of Trees and Shrubs*, by T. R. Peace, with copyright permission from the publisher.

Berry, 1969

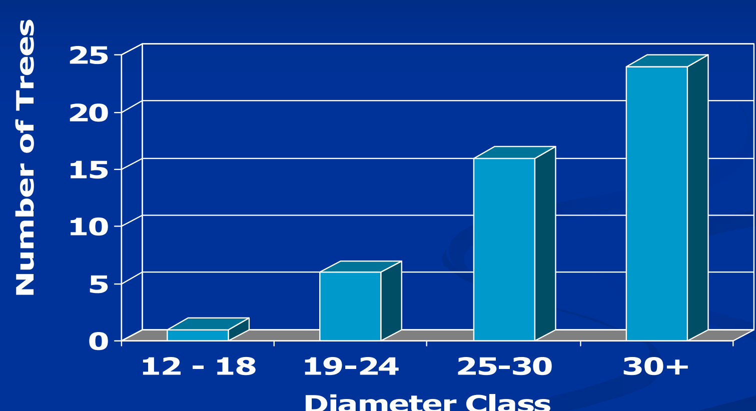
Table 4.—Relationship between infection courts and incidence of infection and volume of decay

Infection court	Infections		Volume of decay	
	No.	*Percent*	*Cu. ft.*	*Percent*
Fire scars	128	26.12	99.20	31.98
Insect wounds	78	15.92	28.00	9.03
→ Dead branch stubs	69	14.08	31.13	10.03
Parent stumps	41	8.37	38.21	12.32
→ Open branch stub scars	31	6.33	39.95	12.88
→ Branch bumps	31	6.33	16.33	5.26
Damaged tops	23	4.69	16.48	5.31
Roots	22	4.49	6.68	2.15
Mechanical injuries	21	4.29	11.87	3.83
Woodpecker injuries	18	3.67	5.96	1.92
Miscellaneous	13	2.65	9.79	3.16
Unknown	15	3.06	6.61	2.13
Total	490	100.00	310.21	100.00

Decay Incidence by DBH
Random Survey of 1800 Street Trees

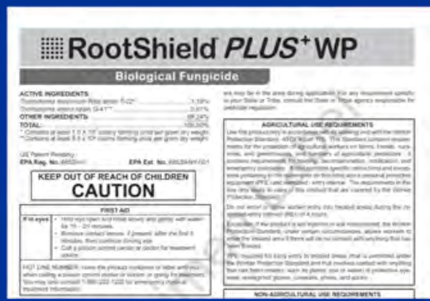


Decay Severity by Diameter
SW/SR = 0.3 or less



Treatment of Wounds with *Trichoderma sp.*

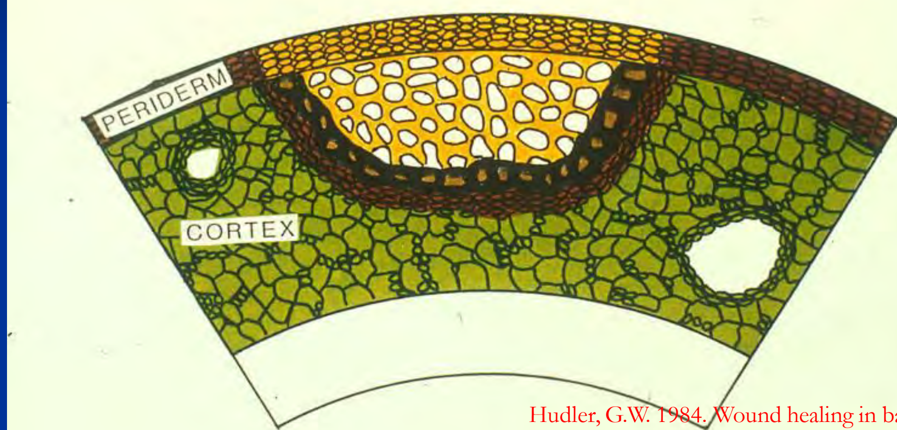
- Extensive literature on effectiveness on wound treatment
- May not be long lasting enough
- F. Schwarze claims curing trees with decay with “tailored” *Trichoderma* treatment



Two Responses to Wounding

- Closure/Sealing
  - Callus
  - Woundwood
- Compartmentalization
  - Reaction zones
  - Barrier zones

Bark or Wound Periderm



G.W. Hudler

Hudler, G.W. 1984. Wound healing in bark of woody plants. *Journal of Arboriculture* 10:241–245.

Wound Closure

Callus and Woundwood

Callus or Woundwood?

Callus or Woundwood?
Everyone is WRONG!

University Extension Publication

it is needed as a sign to indicate the wound has been treated. Otherwise, do not paint over the wound.

Treating Old Wounds

If callus has begun to form, carefully remove the old dead bark until the callus layer is found. Do not cut the callus or shape the wound. If callus is absent, treat the wound as if it were a recent injury.

CALLUS FORMATION

Biology of Callus and WW

Urbanforestryllc.com

CONTINUING EDUCATION UNIT

Biology and Assessment of Callus and Woundwood

By Christopher J. Luley

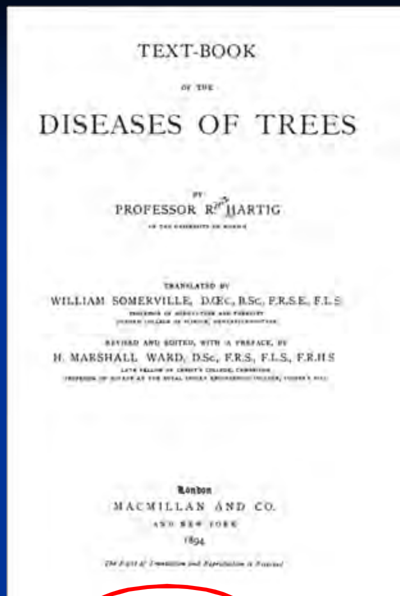
Objectives

- Explain the circumstances in which callus and woundwood are formed
- List the environmental and physical conditions that affect growth of callus and woundwood
- Understand the implications of callus or woundwood on tree risk assessment

CEUs for this article apply to Certified Arborist, Utility Specialist, Municipal Specialist, Tree Worker Climber/Aerial Lift Specialist, and the BCMA science category.

called upon to evaluate tree response to wounding in risk and Plant Health Care assessments (Figure 1).

Historically, wound response has been divided into wound closure (new growth formed after the wounding event and discussed in this article) and compartmentalization (various responses of pre-existing tissues) (Shigo 1984). Two terms have dominated the discussion of wound closure, *callus* and *woundwood*. Understanding these terms has been a source of confusion for both scientists and arborists. This article will review the biology of callus and woundwood formation, and demonstrate how this knowledge can provide diagnostic information about overall tree health, reaction to pathogens and insect pests, tree stability, and forensics.


TEXT-BOOK

OF THE

DISEASES OF TREES

BY

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London

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AND NEW YORK

1894

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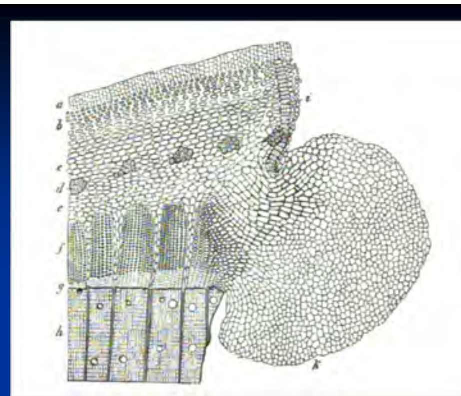


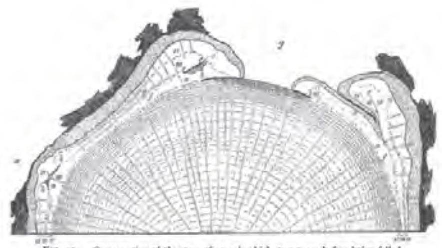


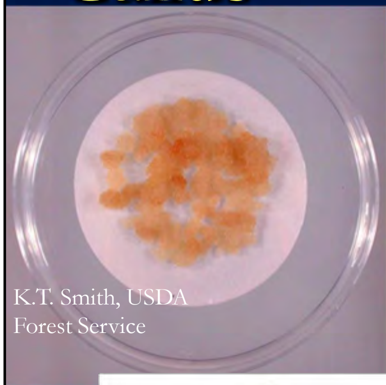
FIG. 134.—Cross-section of the stem of an oak which, two years before being felled, had ruptured at several places in the cortex in consequence of much-augmented growth. *x* and *y*, two places where the cortex had ruptured; *a* to *h*, new investing layers formed by occlusion with their cortex, *d*; *c*, callus; *e* to *e*, lower surface of the loosened cortex, the cambium of which has also produced new growth.

Callus

- Initially forms adjacent to a wound

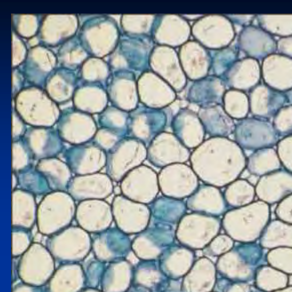
Shigo 1984

Callus

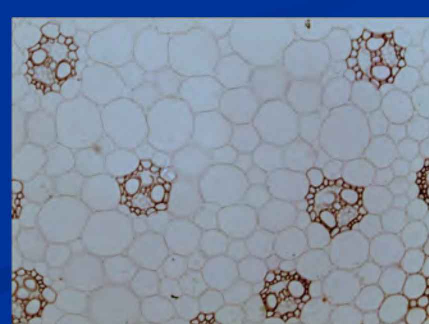


- Kuster (1913) "homogenous, parenchymatic", very thin, walled undifferentiated cells
  - Shigo (1984) initially lacking lignin
- Fink 1999 "Undifferentiated parenchymatic proliferations frequently of ***mixed origin*** but having a homogeneous appearance"
- Ikeheuchi et al 2013 Disorganized cell masses that can have varying levels of genetic and cellular differentiation

Parenchyma Cells



- Thin walled living plant cells
- Parenchyma-tissue made up of parenchyma cells
- Ray parenchyma-collection of cells



Callus

- Thin walled, undifferentiaed, mostly round cells that initially lack lignin
- Forms days/weeks after a wound
- Formed by
  - Vascular cambium
  - Sapwood ray parenchyma, and/or
  - Bark (phloem) parenchyma

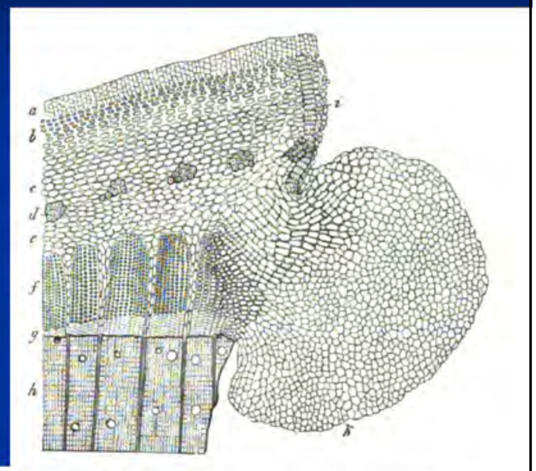
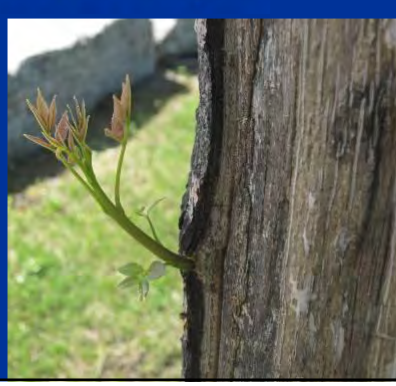


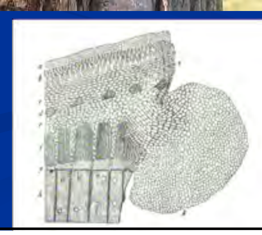
FIG. 132.—The formation of callus on the edge of a wound on an oak-branch. *a*, periderm; *b*, collenchyma; *c*, outer cortex; *d*, primary bundles of hard bast; *e*, cortical parenchyma; *f*, soft bast; *g*, cambium; *h*, wood; *i*, "wound-cork" formed by the outer cortex; *k*, callus.

Callus

Totipotent

•Blank slate
•Can form vascular cambium, roots, shoots or whole plant





Callus

1. May differentiate to form vascular cambium
2. Covers VC while it regains function

- Short-lived
  - Becomes lignified and loses mitotic ability
  - Sloughed off as woundwood grows

Shigo 1984

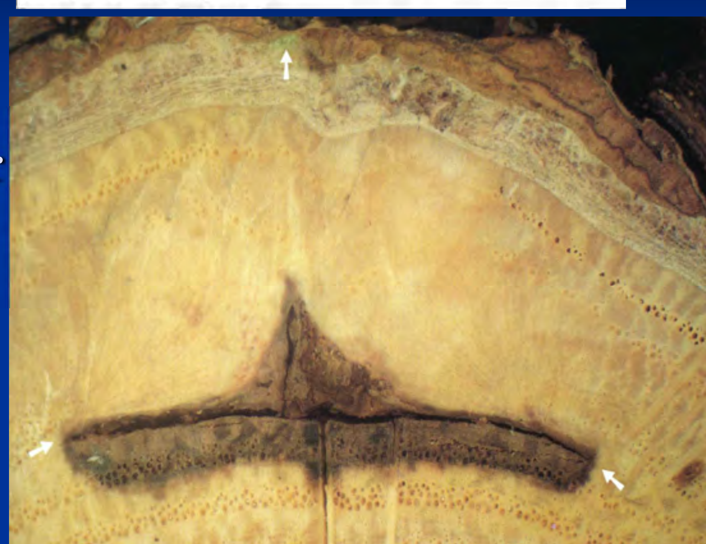
Woundwood forms from
1. Vascular cambium (VC)
2. VC differentiated from Callus

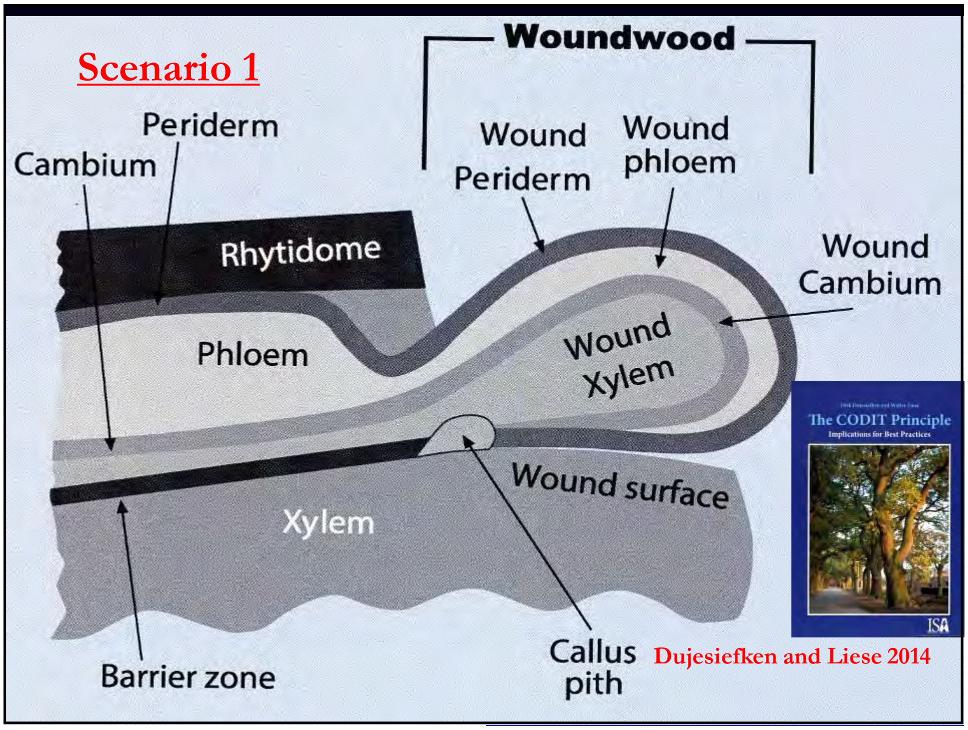
- Initially shorter, denser cells
- Less vessels
- Resin canal increase in conifers

Wound-wood

Besides a thin walled, homogeneous callus parenchyma, many plants, after injury, produce tissues of other kinds, which become similar to wood tissue through a develpment of tracheal elements. The tissue resembling wood, which is formed after injury, is distinguished from normal xylem by its simple histology. We will term it wound-wood and for this reason add it to the list of kataplasms.

Kuster 1913





Callus Forms VC Directly

Annals of Botany **89**: 773–782, 2002
doi:10.1093/aob/mcf137, available online at www.aob.oupjournals.org

Developmental Stages and Fine Structure of Surface Callus Formed after Debarking of Living Lime Trees (*Tilia* sp.)

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Wounding of trees by debarking during the vegetative period sometimes results in the formation of callus tissue which develops over the entire wound surface or on parts of it. This light and transmission electron microscopy study of living lime trees found that the formation of such a surface callus is subdivided into three stages. During the first stage, numerous cell divisions take place in regions where differentiating xylem remains at the wound surface after debarking. This young callus tissue consists of isodiametric parenchymatous cells. Cambium cells, sometimes also remaining at the wound surface, collapse and do not contribute to callus formation. During the second stage, cells in the callus undergo differentiation by forming a wound periderm with phellem, phellogen and phelloderm. In the third stage, a cambial zone develops between the wound periderm and the xylem tissue laid down prior to wounding. This process is initiated by anticlinal and periclinal divisions of a few callus cells only. Later this process extends tangentially to form a continuous belt of wound cambium. Subsequently, this cambium produces both wound xylem and wound phloem and thus contributes to further thickening.

Key words: Debarking, wound reactions, cambium, surface callus, tissue differentiation, *Tilia* sp., light microscopy, electron microscopy.

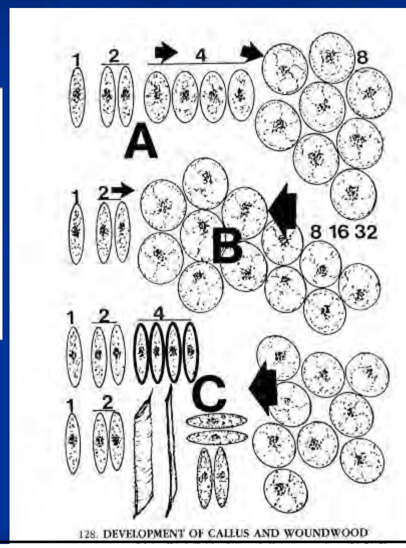
Callus Forms VC Directly DeBarked Tilia

1. Young callus forms as isodiametric parenchymatous cells
   - Sapwood parenchyma
2. Cambial cells remaining at surface die
3. Callus forms wound periderm (Bark)
4. Cambial zone forms under new periderm
   - From callus

- New cambium produces xylem and phloem

Callus can form vascular cambium which then forms wound wood directly

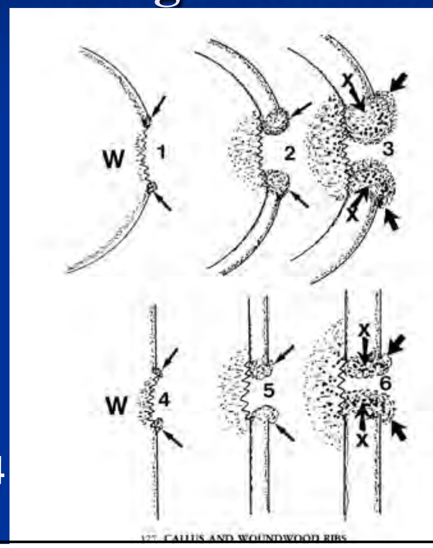
Scenario 2. Callus Covers VC and VC Regains Function



Shigo, 1984

Callus can form vascular cambium which then forms wound wood directly

Callus may Seal small wounds Sloughed off as wound ages and VC regains function



Shigo, 1984

Correct Answer?

- Both WW and Callus
  - Early in the wound sealing process

With Time Normal Wood Develops

Woundwood
Normal wood eventually forms

Conifers

- Form traumatic resin canals in woundwood
- Do NOT form surface callus and woundwood

Wound and Callus
Why do I Care?
Plant Health Care, Pest Resistance, Decay Assessment, Forensics and More

- Indicator of response
- Predictor of internal decay resistance

Woundwood Seals a Wound

- The Seal not the Heal
- Callus/WW seal small wounds quickly
- Injection treatments may impact callus and woundwood formation

Woundwood Seals a Wound Sets the Stage for "Frost Cracks"

Ribs and "Frost Cracks"
Related to old wound and WW
Indicate an internal defect, possibly decay

Rams Horns
The wound will never seal

- Woundwood may be stronger than normal wood (Kane and Ryan 2003)
- REALLY needs more study

Shigo 1984

Woundwood has fungicidal properties

- Phenolic extractives of wound-associated wood of beech and their fungicidal effect (Vek, Oven, and Humar, 2012)

Callus and Woundwood
Forms quickest when trees are actively growing

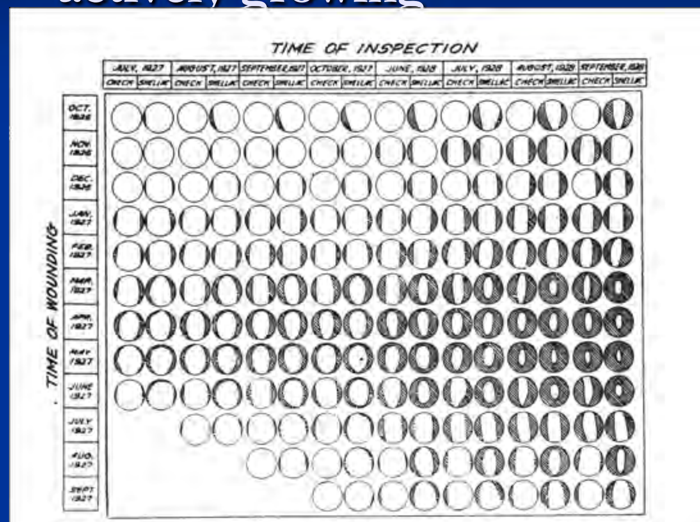
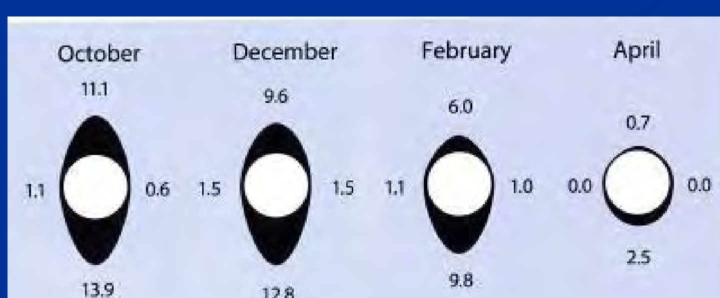


FIGURE 5.—Successive stages of callus growth for each wound on *Acer rubrum* No. 4

Marshall, R. P. 1931. The relationship of season of wounding and shellacking to callus formation in tree wounds. USDA Technical Bulletin 246. 29 p.

Impact of Time of year on Wound Closure

Wounds made in the fall seal slowest and may have dieback associated with the injury



Dujesiefken and Liese 2014

TABLE 1.—CLOSURE OF INCREMENT BORER HOLES[1]

Species	Holes made in fall: Healed after 1 growing season	Holes made in fall: Healed after 2 growing seasons	Holes made in spring: Healed after 1 growing season	Holes made in spring: Healed after 2 growing seasons
	Percent			
Eastern cottonwood	98	100	100	100
Green ash	100	100	100	100
Nuttall oak	81	97	98	100
Sweetgum	75	98	100	100
Sugarberry	20	78	18	75

[1]Each percentage based on 40 holes, except that Nuttall oak bored in fall was represented by 36 holes.

Toole and Gammage, 1959. Forestry

Wound Sealing
High Humidity Protection Promote Callus and Woundwood Formation

POLYETHYLENE PLASTIC WRAP FOR TREE WOUNDS: A PROMOTER OF WOUND CLOSURE ON FRESH WOUNDS

-McDougall and Blanchette, 1996

- Effect goes away after 1 week
- Species effects present

Callus and Borer Resistance

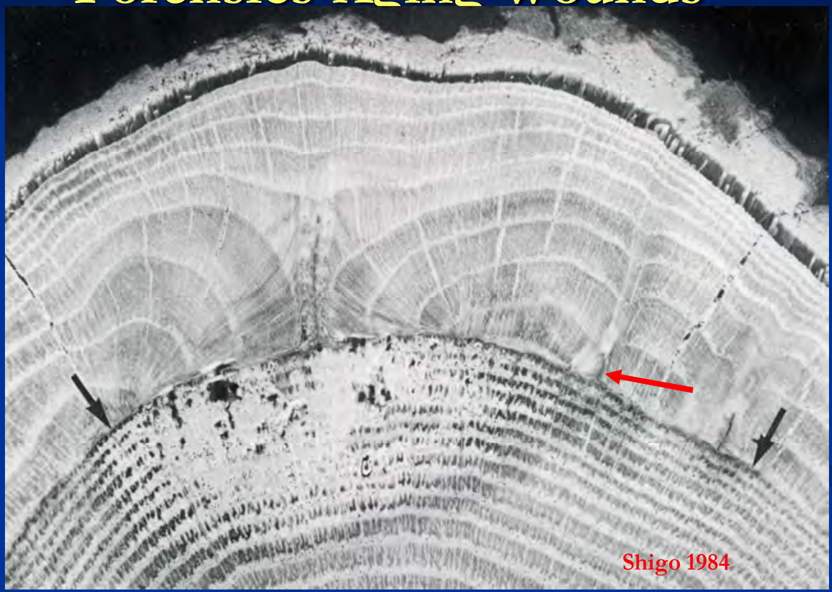
Fierke and Stephen. 2008. Callus formation and bark moisture as potential physical defenses of northern red oak, *Quercus rubra*, against red oak borer, Enaphalodes rufulus (Coleoptera: Cermabycidae). Canadian Entomolgist 140:149-157

Callus, Woundwood and Borer Resistance

Assessment of Woundwood in Tree Health and Stability

- Rate of Formation
- Age of Wound/Decay
  - Forensics
- Presence or Absence

Forensics-Aging Wounds



Aging EAB Infestation

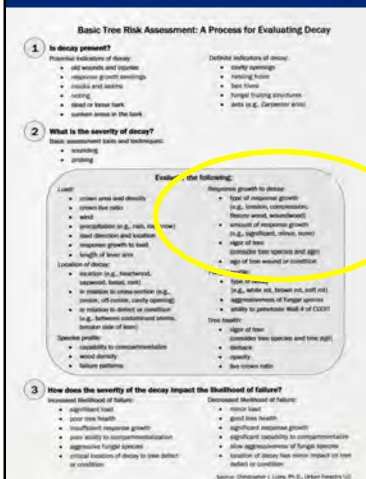
Forensics

WW is a Type of Response Growth

Presence or Absence is a Key PHC Diagnostic

1. Lack of Vitality
2. Pathogen or Insect Attack
3. Location-supply shadow

Decay Assessment-Presence/Absence of Woundwood Response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- sunken areas in the bark

Definite indicators of decay:
- cavity openings
- nesting holes
- bee hives
- fungal fruiting structures
- ants (e.g., Carpenter ants)

2 What is the severity of decay?

Basic assessment tools and techniques:
- sounding
- probing

Evaluate the following:

Load:
- crown area and density
- crown live ratio
- wind
- precipitation (e.g., rain, ice, snow)
- load direction and location
- response growth to load
- length of lever arm

Location of decay:
- location (e.g., heartwood, sapwood, basal, root)
- in relation to cross-section (e.g., center, off-center, cavity opening)
- in relation to defect or condition (e.g., between codominant stems, tension side of lean)

Species profile:
- capability to compartmentalize
- wood density
- failure patterns

Response growth to decay:
- type of response growth (e.g., tension, compression, flexure wood, woundwood)
- amount of response growth (e.g., significant, minor, none)
- vigor of tree (consider tree species and age)
- age of tree wound or condition

Fungal profile:
- type of decay (e.g., white rot, brown rot, soft rot)
- aggressiveness of fungal species
- ability to penetrate Wall 4 of CODIT

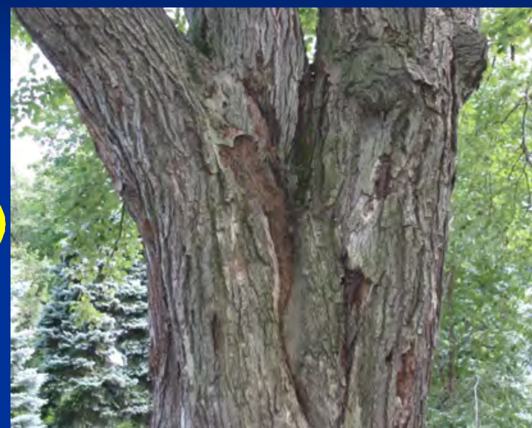
Tree health:
- vigor of tree (consider tree species and tree age)
- dieback
- opacity
- live crown ratio

3 How does the severity of the decay impact the likelihood of failure?

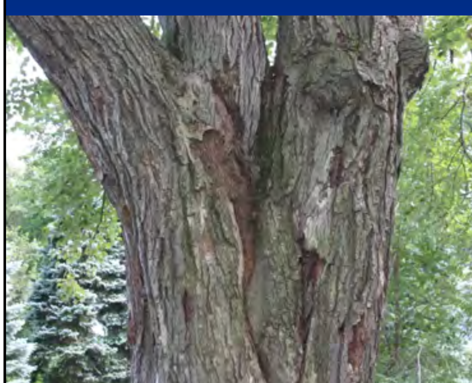
Increased likelihood of failure:
- significant load
- poor tree health
- insufficient response growth
- poor ability to compartmentalization
- aggressive fungal species
- critical location of decay to tree defect or condition

Decreased likelihood of failure:
- minor load
- good tree health
- significant response growth
- significant capability to compartmentalize
- slow aggressiveness of fungal species
- location of decay has minor impact on tree defect or condition

Source: Christopher J. Luley, Ph.D., Urban Forestry LLC



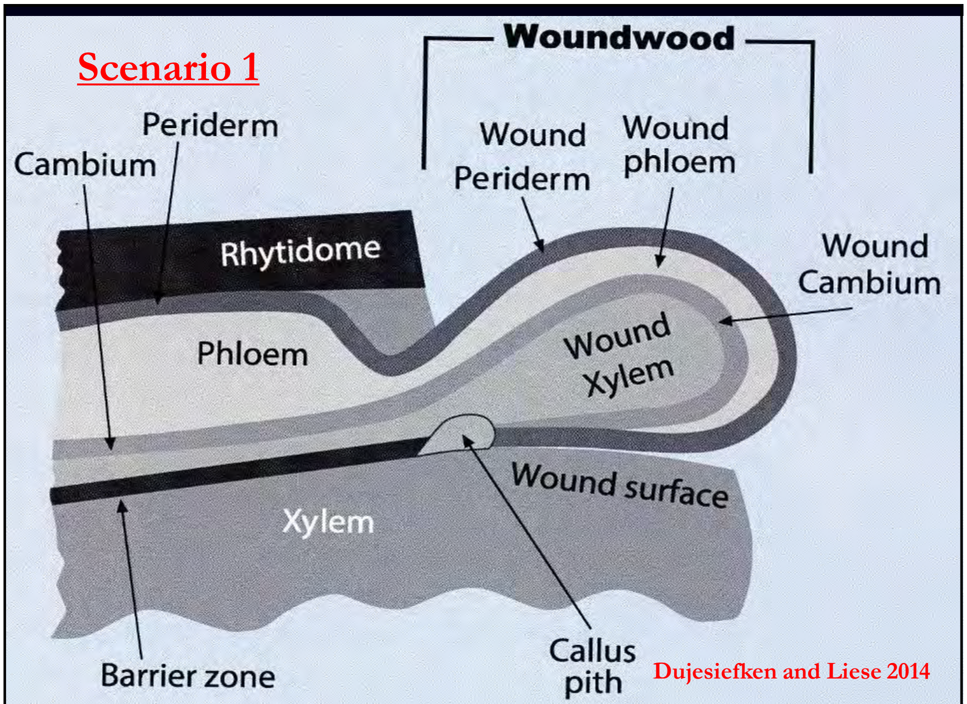
Decay Assessment-Presence/Absence of Woundwood



Diagnostics
Absence of WW

Presence/Absence of Response Growth including Woundwood

Scenario 1



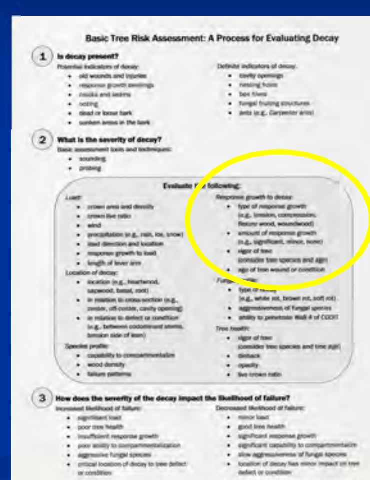
Dujesiefken and Liese 2014

Basic Wood Anatomy

- Rays-
  - Living parenchyma cells
  - React to decay fungi invasion
  - Attached to phloem and sugar source!

Presence or Absence of WW

- Proxy for tree defense against decay spread



Basic Tree Risk Assessment: A Process for Evaluating Decay

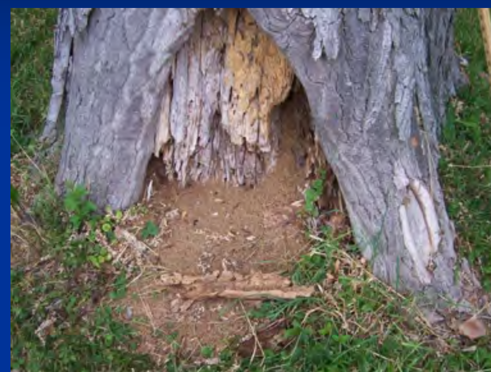
1. Is decay present?
2. What is the severity of decay?

Evaluate the following:

3. How does the severity of the decay impact the likelihood of failure?

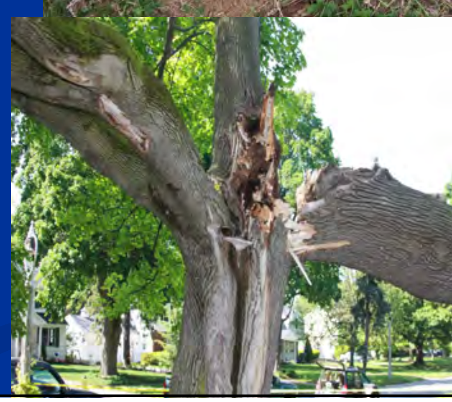
Source: Christopher J. Luley, Ph.D., Urban Forestry LLC

-Low Failure Rate?



(Kane and Ryan 2003)

The Lag



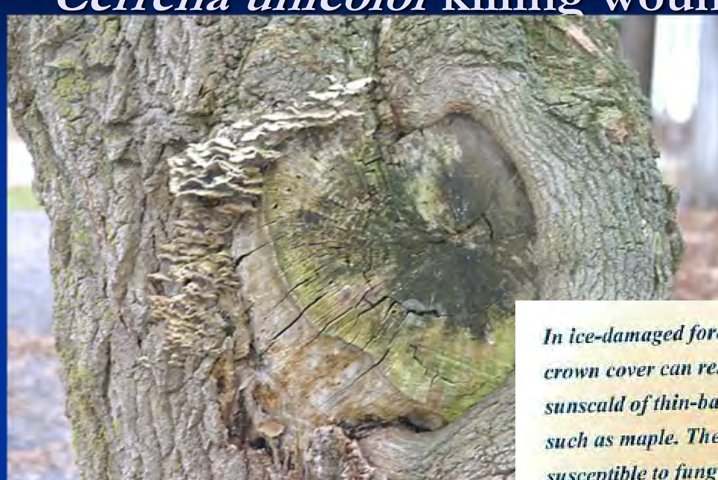
WW is a Type of Response Growth Presence or Absence is a Key PHC Diagnostic

1. Lack of Vitality
2. **Pathogen or Insect Attack**
3. Location-supply shadow

Potential Indicators
Old Cankers

Eutypella canker
Killing Woundwood

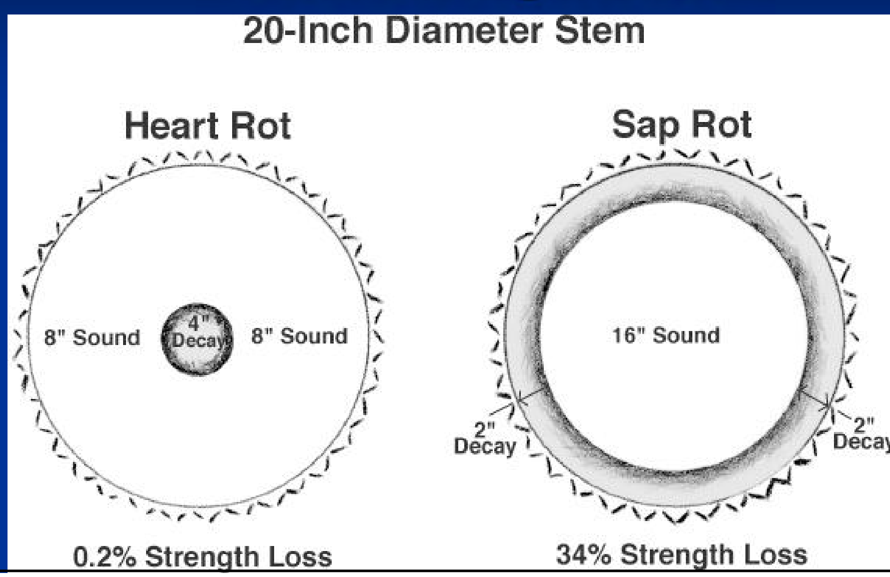
Cerrena unicolor killing woundwood



In ice-damaged forests, reduced crown cover can result in substantial sunscald of thin-barked tree species such as maple. These trees are then susceptible to fungi such as Cerrena unicolor*, a sap rot that commonly attacks sun-scalded bark and can kill young trees.*

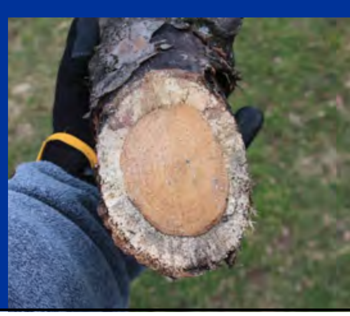
Schizophyllum commune

Sap Rot Importance
Stem Strength Loss

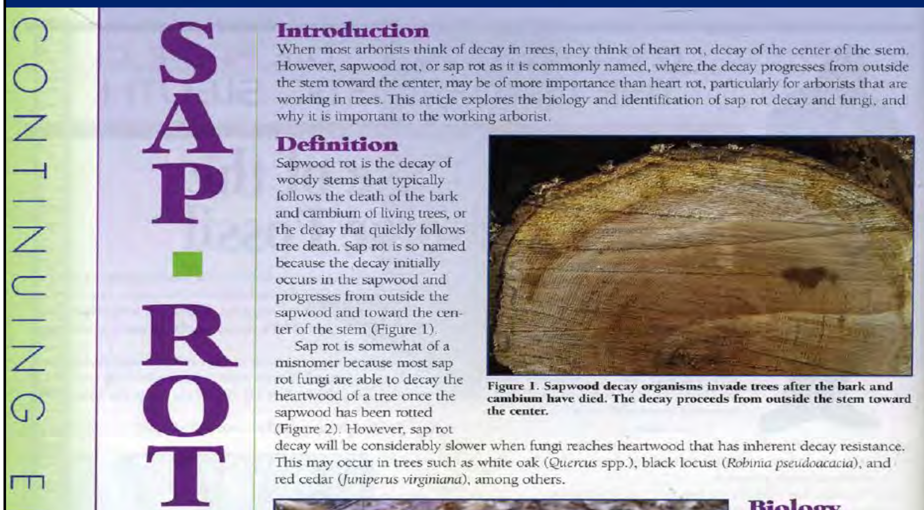


Sap Rot Assessment

- Safest=Assume the stem is completely decayed



Urbanforestryllc.com



CONTINUING E

SAP · ROT

Introduction

When most arborists think of decay in trees, they think of heart rot, decay of the center of the stem. However, sapwood rot, or sap rot as it is commonly named, where the decay progresses from outside the stem toward the center, may be of more importance than heart rot, particularly for arborists that are working in trees. This article explores the biology and identification of sap rot decay and fungi, and why it is important to the working arborist.

Definition

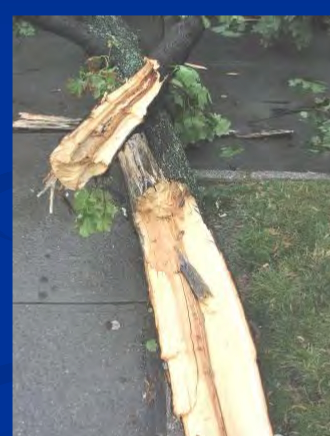
Sapwood rot is the decay of woody stems that typically follows the death of the bark and cambium of living trees, or the decay that quickly follows tree death. Sap rot is so named because the decay initially occurs in the sapwood and progresses from outside the sapwood and toward the center of the stem (Figure 1).

Sap rot is somewhat of a misnomer because most sap rot fungi are able to decay the heartwood of a tree once the sapwood has been rotted (Figure 2). However, sap rot decay will be considerably slower when fungi reaches heartwood that has inherent decay resistance. This may occur in trees such as white oak (*Quercus* spp.), black locust (*Robinia pseudoacacia*), and red cedar (*Juniperus virginiana*), among others.

Figure 1. Sapwood decay organisms invade trees after the bark and cambium have died. The decay proceeds from outside the stem toward the center.

Biology

Sap Rot-Living Trees



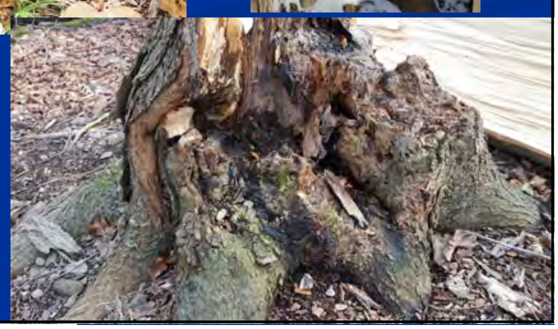
Sap Rot Assessment
Sounding Not Useful

for Quantitative Assessment

Case Hardening

- The colour of the wound face may also be used to determine internal condition. Dark wound faces can indicate more defect than dry, white-faced wounds, which usually have little decay or stain associated with them.

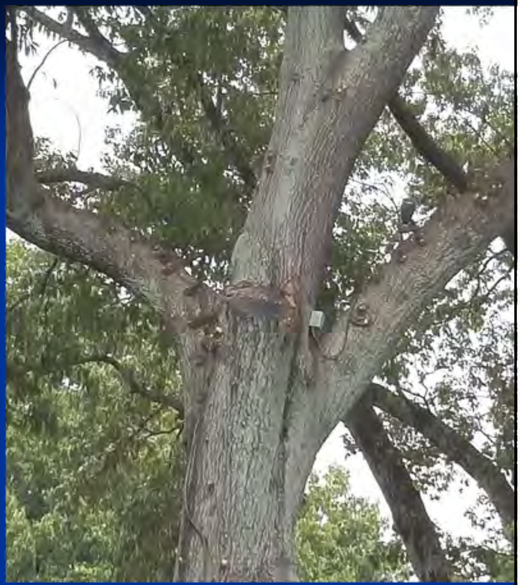
Kretzschmaria deusta killing woundwood and decaying wood



WW is a Type of Response Growth Presence or Absence is a Key PHC Diagnostic

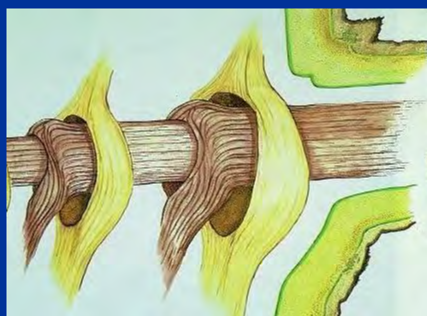
1. Lack of Vitality
2. Pathogen or Insect Attack
3. **Location-supply shadow**

Supply Shadow Absence of WW



Woundwood Formation
Basipetal Flow (Leaves to Roots)

- Wound Location
- ‘Supply Shadow”



Supply Shadow

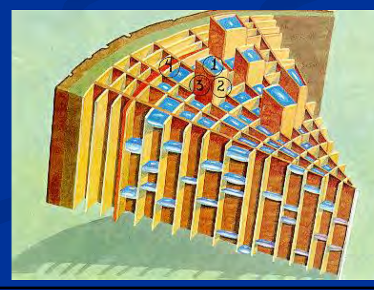
Woundwood Formation
Basipetal Flow (Leaves to Roots)

- Wound Location
- 'Supply Shadow"
- Large wounds
  - More WW on sides of wound

EAB Assessment
Supply Shadow?

- Pruning wounds and branch unions

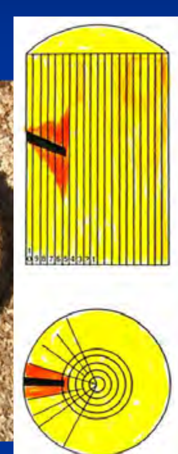
Two Responses to Wounding



1. Closure
   - WW and callus

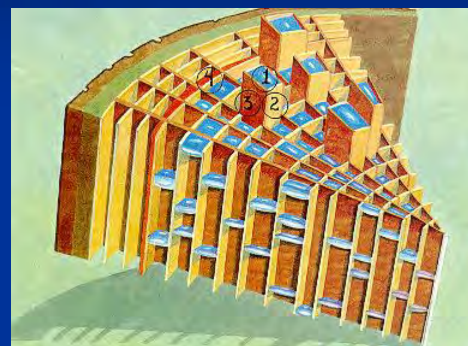
1. Compartmentalization
   - Barrier zone- new tissue layer
   - Reaction zones-existing tissues
     - Aka Boundary zones, Boundary layers
   - Natural boundaries

Reaction to Wounding



Barrier Zones, Reactions Zones and CODIT

- Increasing Decay and Pest Resistance



Wounds that expose <u>heartwood</u> are more likely to heart rot type decay

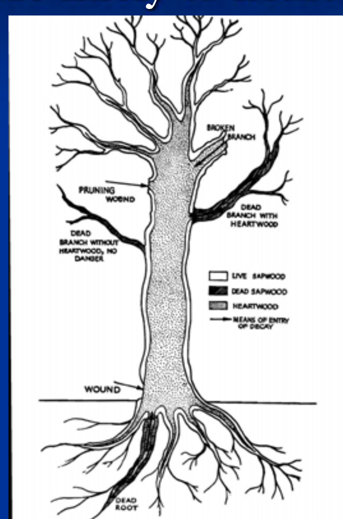
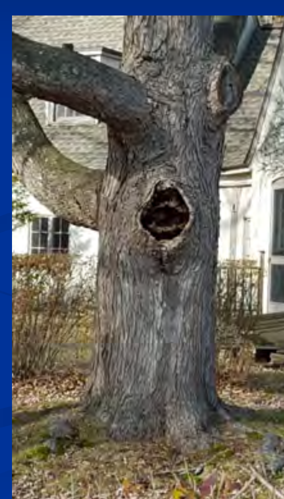


Figure 1 — Methods by which decay enters a tree.
From *Pathology of Trees and Shrubs*, by T. R. Peace, with copyright permission from the publisher.



Basic Wood Anatomy

- Heartwood
  - No living cells!
  - Some heartwood is more resistant decay
  - Heartwood still reacts to wounding

Heartwood Resistance to Decay

- **USDA. 1967.Comparative decay resistance of heartwood of native species. FPL-0513**
  - **Greatest resistance of heartwood to decay is in the butt of a tree**

Resistant or very resistant	Moderately resistant	Slightly or nonresistant
Baldcypress (old growth)[1]	Baldcypress (young growth)[1]	Alder
Catalpa	Douglas-fir[2]	Ashes
Cedars	Honeylocust[2]	Aspens
Cherry, black	Larch, western	Basswood
Chestnut	Oak, swamp chestnut	Beech
Cypress, Arizona	Pine, eastern white[1]	Birches
Junipers	Pine, longleaf[1]	Buckeye[2]
Locust, black[3]	Pine, slash[1]	Butternut
Mulberry, red[3]	Tamarack	Cottonwood
Oak, bur		Elms
Oak, chestnut		Hackberry
Oak, Gambel		Hemlocks
Oak, Oregon white		Hickories
Oak, post		Magnolia
Oak, white		Maples
Osage-orange[3]		Oak (red and black species)[2]
Redwood		Pines (most other species)[2]
Sassafras		Poplar
Walnut, black		Spruces
Yew, Pacific[3]		Sweetgum[2]
		Sycamore
		Willows
		Yellow-poplar

Ripewood

Heartwood that is not more resistant to decay

False Heartwood

Basic Wood Anatomy

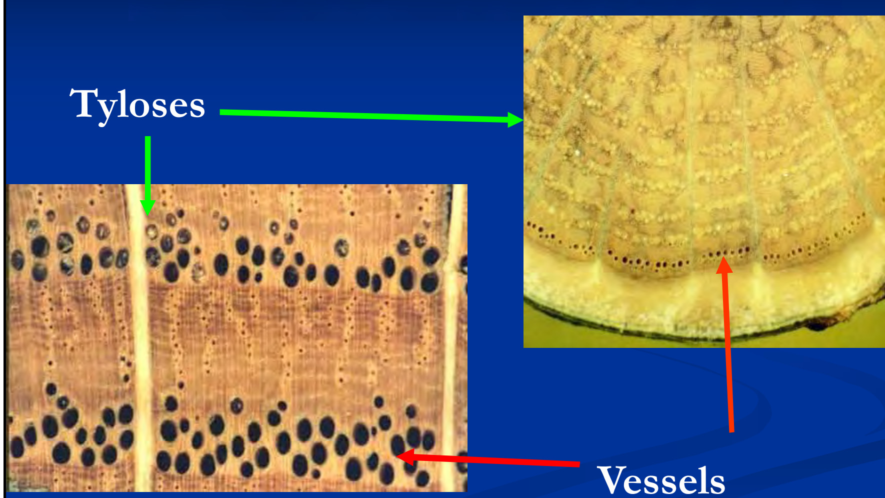
- Sapwood or
  - Xylem
  - Not inherently resistance to decay
  - Resistance due to living cells

Sapwood

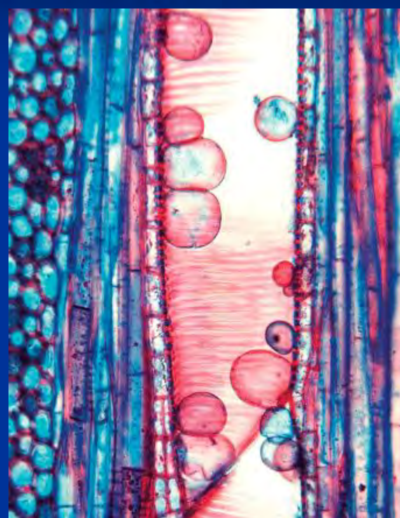
We believe that aeration and moisture effects are primarily responsible for the observed patterns of establishment, but we are still unable to exclude the more widely held view that they are dictated by the host responses of living sapwood

(Boddy & Rayner, 1983)

Vessels-conducting water

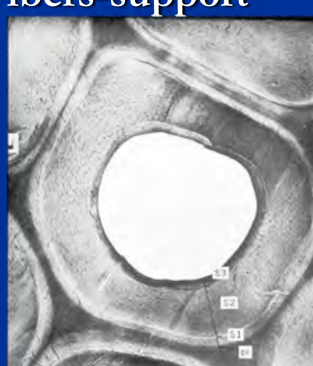


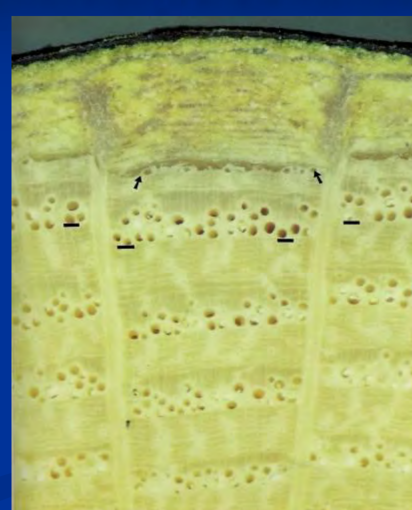
Tyloses
Formed by Axial Parenchyma



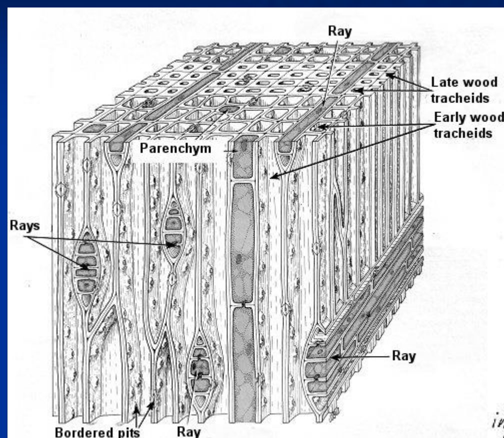
Wood Structure
Angiosperms (Hardwoods, Deciduous)

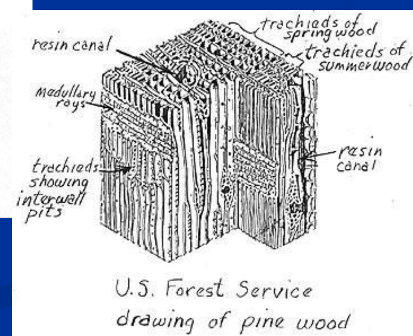
- Vessels-conduct water
- Fibers-support





Conifers-Tracheids



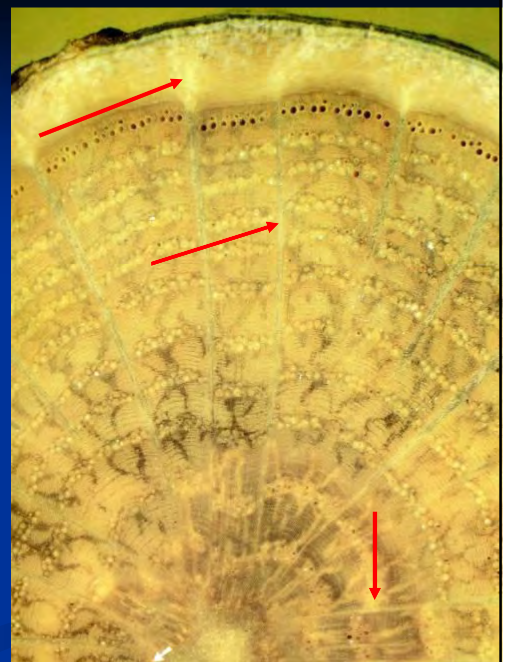


Basic Wood Anatomy

- Rays-
  - Living parenchyma cells
  - React to decay fungi invasion
  - Attached to phloem and sugar source!

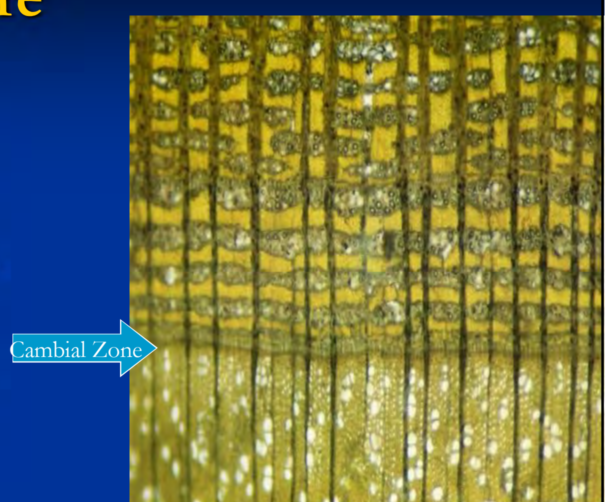
Wood Structure

- Rays-living parenchyma cells in wood
  - Radial arrangement (Medullary rays- in and out to center of the tree)
  - Axial arrangement (up and down)



Wood Structure

- Cambium
  - Lateral Meristem
- Phloem to the outside
- Xylem to the inside



Shigo 1994

Basic Wood Anatomy

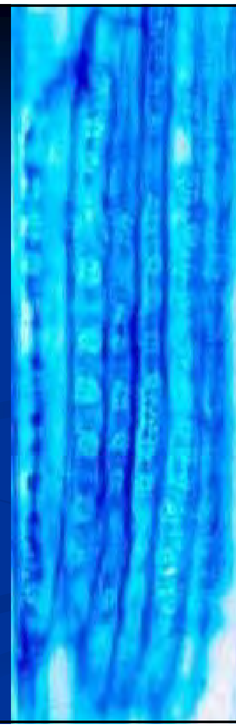
- Cambial Zone

Basic Wood Anatomy

- Phloem
  - Inner bark
  - No structural importance
  - Note rays
  - Note lighter color

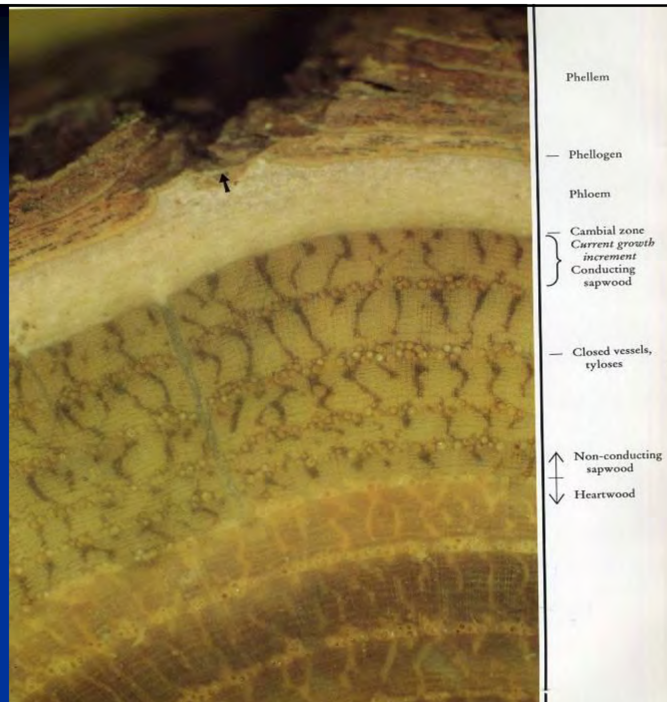
Sieve Tube Elements

- Movement of sugars in the phloem requires energy



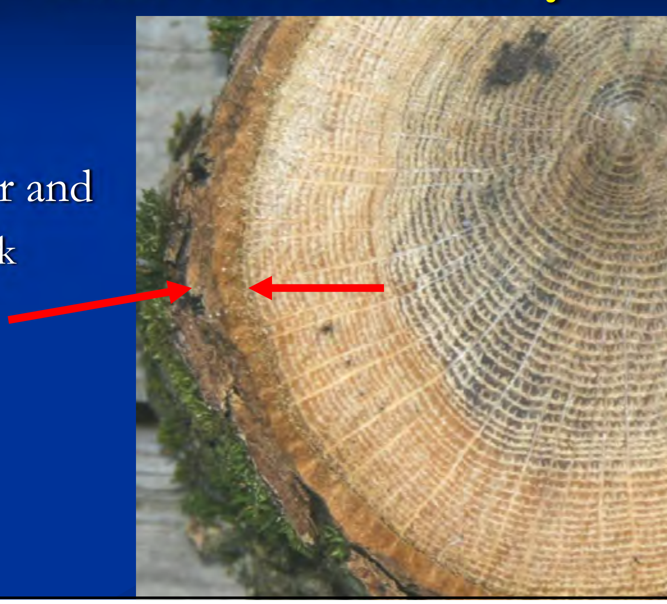
Basic Wood Anatomy

- Bark
  Cambium
  - Trees have 2 cambial layers
  - Phellogen

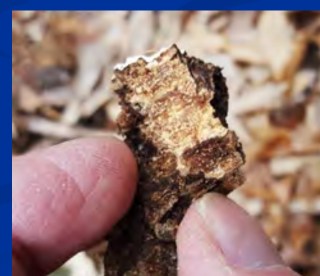


Basic Wood Anatomy

- Bark
  - Inner and Outer bark



Identification and Interpretation?



Dendrothele species Typically Host Specific

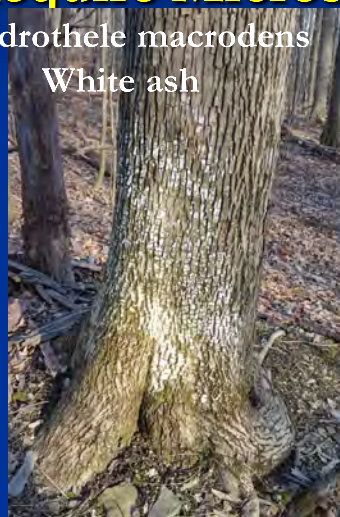
- Widely distributed
- Host specific
- Able to degrade suberin
- Most trees species have one
  - *Ostrya*
  - Hickory
  - White oak
  - Ash
- Basidiomycetes/
  - Agaricales

Dendrothele species

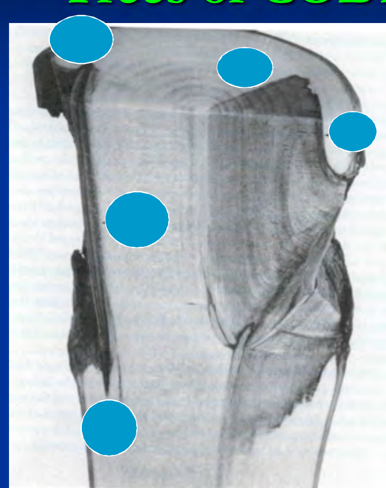
Pignut hickory

White oak

Dendrothele species
Cause of Smooth Patch
Require Microscopic ID to Species



Compartmentalization of Decay in Trees or CODIT



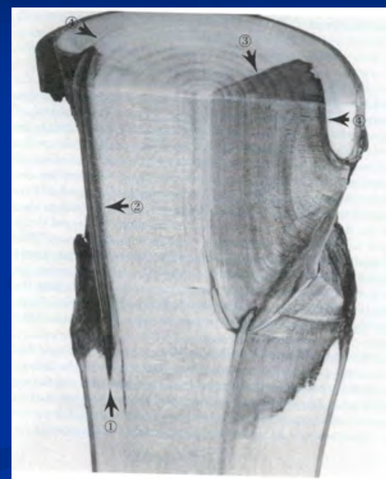
CODIT
In Order of Increasing Strength!

Walls 1-3 Reactions zones or Boundary layers

- Wall 1 = Vessels and tracheid plugging
- Wall 2 = Heartwood and inner growth rings
- Wall 3 = Rays

Strongest Formed by Cambium after Wounding

- Wall 4 = Barrier zone



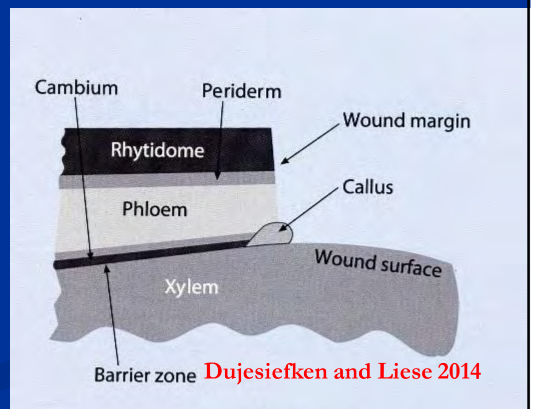
WALL 4

- Formed de novo by cambium
- Strongest protection layer
- Designed to keep new wood free of decay
  - Physical boundary
  - Chemical boundary
- Larger up and down from the wound
  - Rather than around the wound

Barrier Zone

Barrier Zone-formed by cambium Only forms once at a wound site

- High density of parenchyma cells
- High suberin content



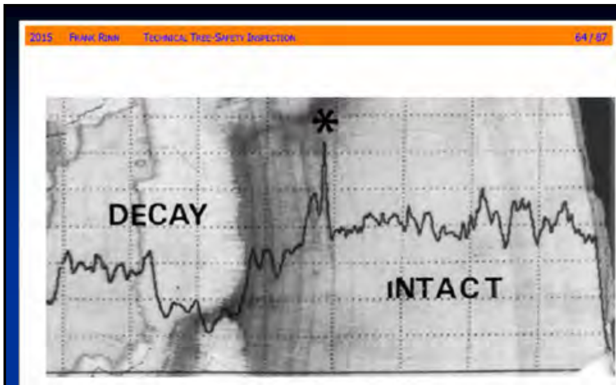
Suberin-Waxy Substance Seals the Wound

- Chemically variable
  - Cork
- Polyphenolic and polyaliphatic
- Water proof
- Fungitoxic
- Physical and Chemical barrier

Barrier Zone

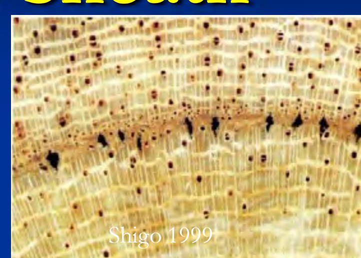
- Formed in annual ring present at the time of wounding
- If dormant forms in next ring

Physical Barrier



Barrier Zone
Protective Sheath

- Highly reactive because of parenchyma cells
- Stronger than reaction zones
- <u>Most decay fungi can't breach barrier zone</u>

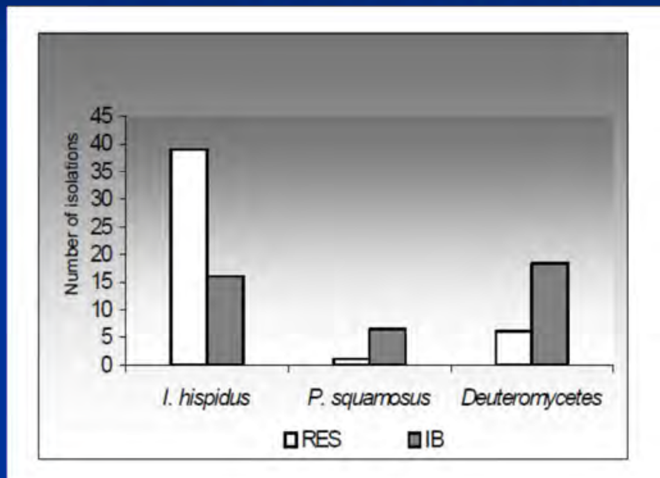


Biological Health
Barrier Zone Strength
Importance of Plant Health Care

Breaching the Barrier Zone can Spread Decay

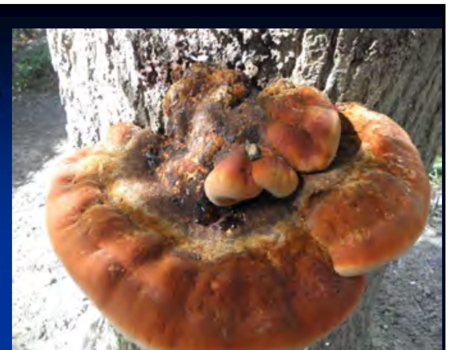
Tom Smiley, Bartlett Tree Experts

Depends on the Fungus Present
Barrier Zone Breach



Kersten and Schwarze 2004

Inonotus hispidus



- Decay grows in then out to cambium
- New Barrier zone forms!!!
- With Woundwood!

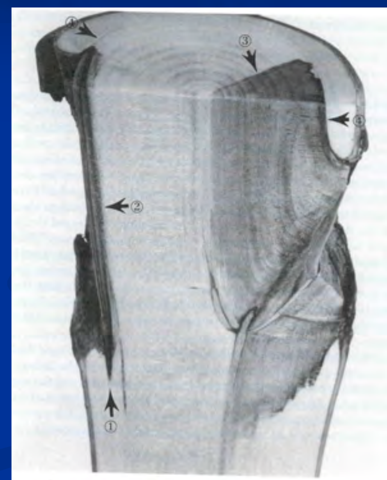
CODIT
In Order of Increasing Strength!

Walls 1-3 Reactions zones or Boundary layers

- Wall 1 = Vessels and tracheid plugging
- Wall 2 = Heartwood and inner growth rings
- Wall 3 = Rays

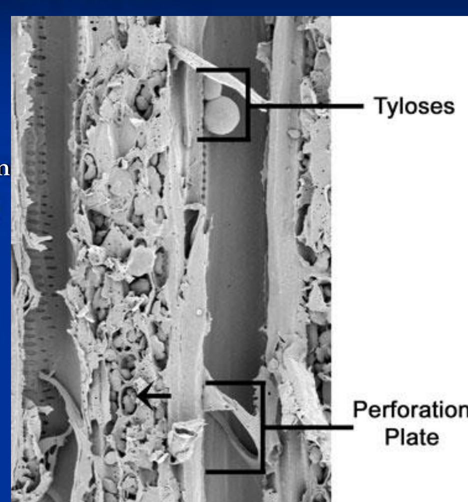
Strongest Formed by Cambium after Wounding

- Wall 4 = Barrier zone



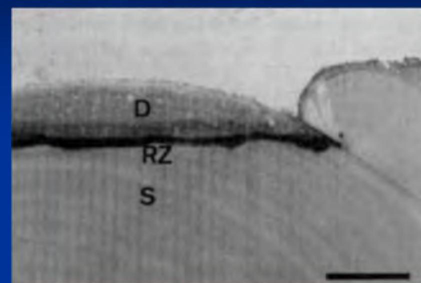
Wall 1 CODIT Details

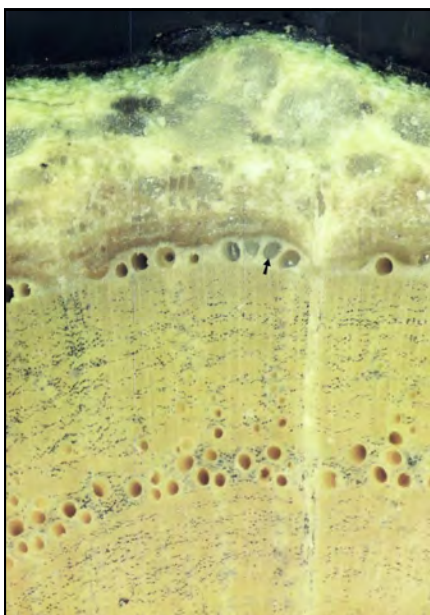
- **Wall 1**
  - **Weakest wall**
    - Tyloses and parenchym
  - **Decay spreads up and down fastest**
    - Up>
  - **Wall 1 can reform as decay spreads**
    - Axial and radial parenchyma

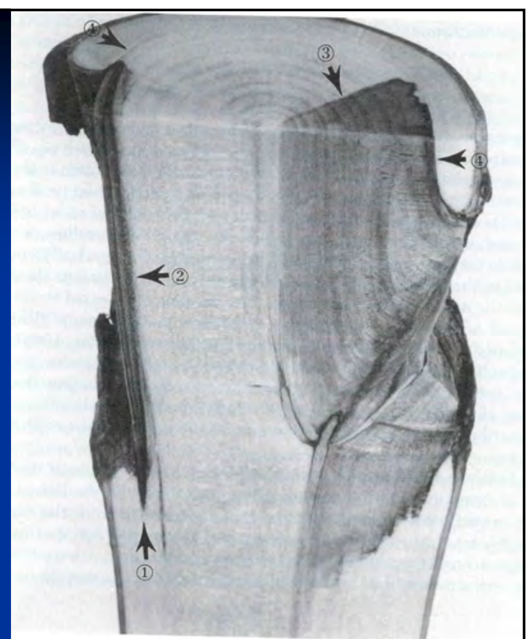


Wall 2 CODIT Details

- Second weakest wall
- Is the reaction zone when Wall 4 fails
- Annual rings
  - Latewood
  - Thick walled and highly lignified
- Heartwood







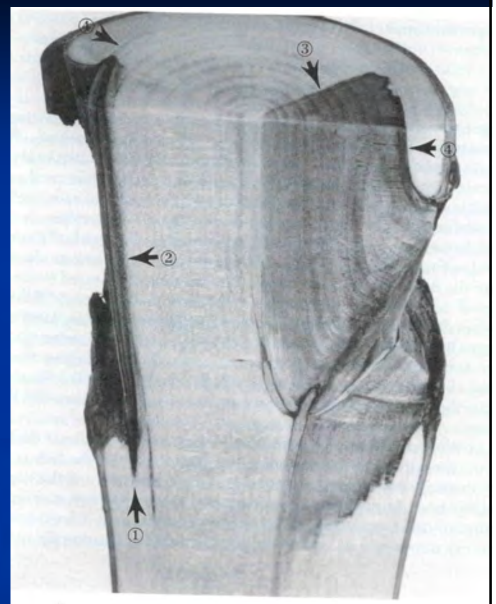
Wall 2

Wall 2

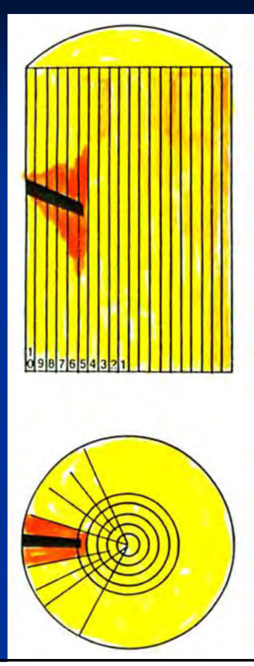
- Heartwood Exposed
- High probability of decay
- No living tissues to respond

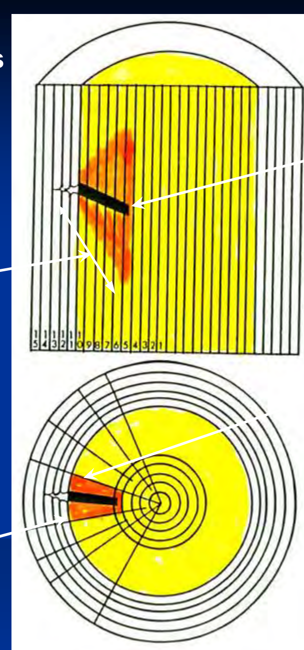
Wall 3
CODIT Details

- Ray Parenchyma
  - Radial
  - Axial
- Second strongest wall
  - Phenolics and free radical
- Will reform along with Wall 1 and 4 if breached
- Strength directly affected by tree health?



Reaction Zones





Wall 1:
Plugs in
Vessels &
tracheids

Wall 2:
previous
growth ring

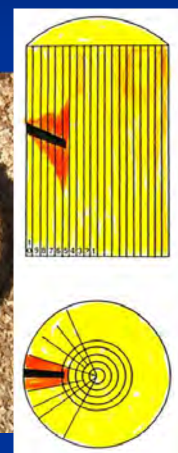
Wall 3:
Rays

Wall 4:
Cells produced
Right after
wounding

Reaction Zones of a “good compartmentalizer

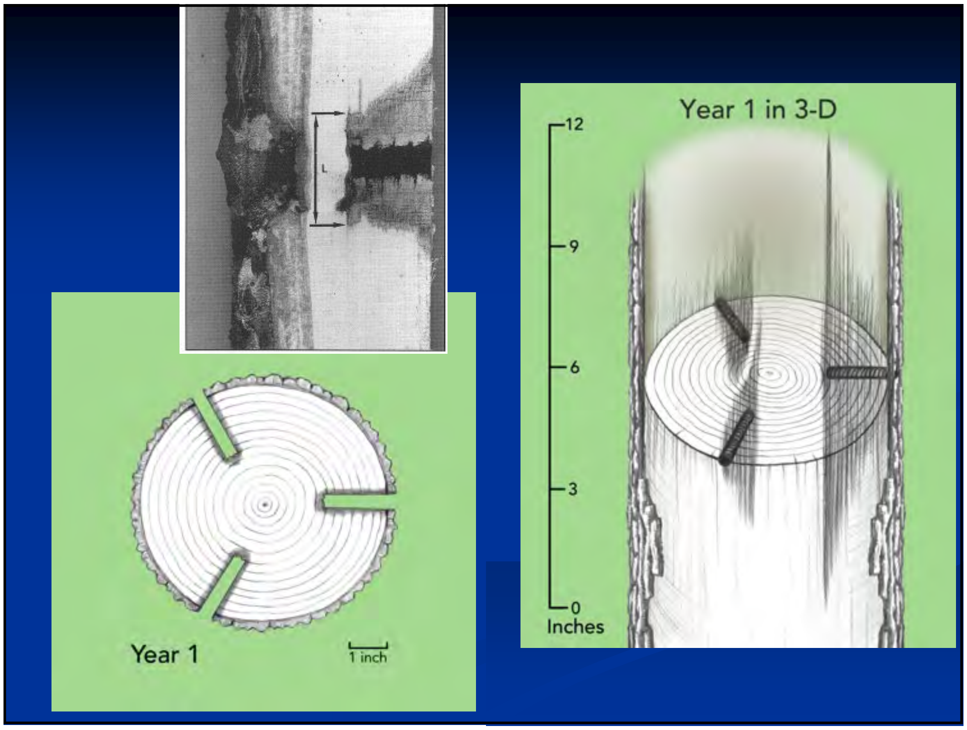
G. W. Hudler

Columns of Discoloration
Drilling



Reaction zones

- Strength of the RZ
- Directly tied to tree biological health
  - Stored reserves in ray parenchyma
- Discolored wood may or may not be decayed



Ash max – 12 inches

TABLE 2.—DISCOLORATIONS TWO GROWING SEASONS AFTER INCREMENT BORING

Species	Holes made in fall: Holes with stain	Holes made in fall: Mean vertical extent[1]	Holes made in spring: Holes with stain	Holes made in spring: Mean vertical extent[1]
	Percent	*Inches*	*Percent*	*Inches*
Eastern cottonwood	92	8.2	73	7.6
Green ash	100	3.2	100	3.0
Nuttall oak	100	9.1	100	11.0
Sweetgum	100	10.7	100	9.5
Sugarberry	100	13.1	100	6.4

[1]Holes with no stain were excluded from the computations.

Toole and Gammage, 1959. J Forestry

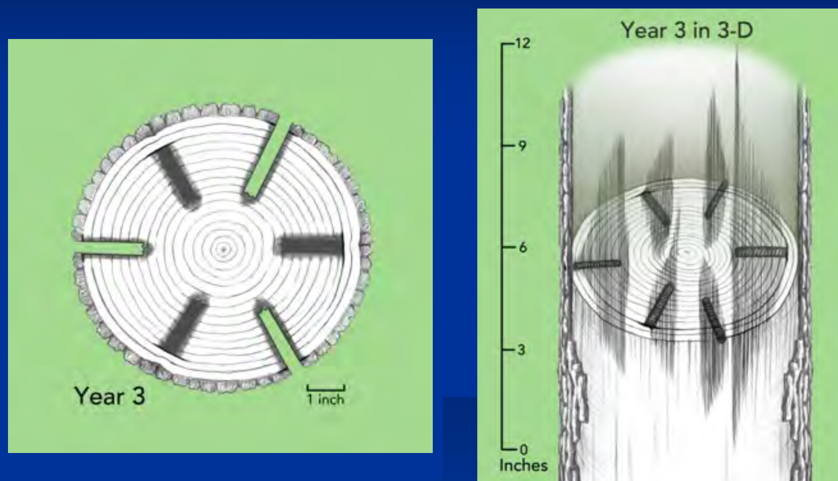
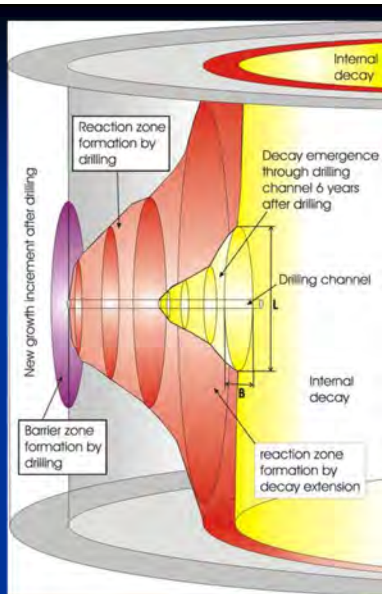


Table 3.—Decay Two Growing Seasons After Increment Boring

Species	Holes made in fall: Holes with rot	Holes made in fall: Mean vertical extent[1]	Holes made in spring: Holes with rot	Holes made in spring: Mean vertical extent[1]
	Percent	*Inches*	*Percent*	*Inches*
Eastern cottonwood	12.5	6.4	0	0
Green ash	2.5	4.0	0	0
Nuttall oak	20.0	1.5	5.0	1.8
Sweetgum	15.0	2.3	80.0	2.6
Sugarberry	22.5	5.1	12.5	4.2

[1]Holes with no decay not included in these figures.

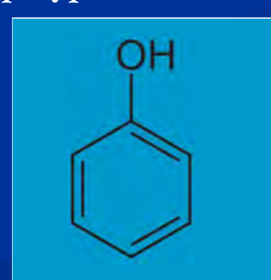


Tom Smiley Bartlett Tree Experts

Tom Smiley Bartlett Tree Experts

Wounding or Breaching of Walls 1-4 Reaction Zones

- Formed by parenchyma cells
- High concentrations of polyphenolics



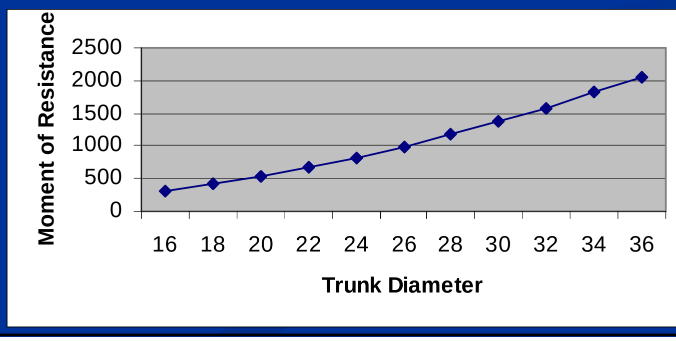
Reaction Zone Formation Whenever Old Barrier Zone or Reaction Zone is Breached

- Wall 1, Wall 2, Wall 3
- Parenchyma of sapwood
- Enzymatic reaction of heartwood

Critical Assessment in Decay Evaluation

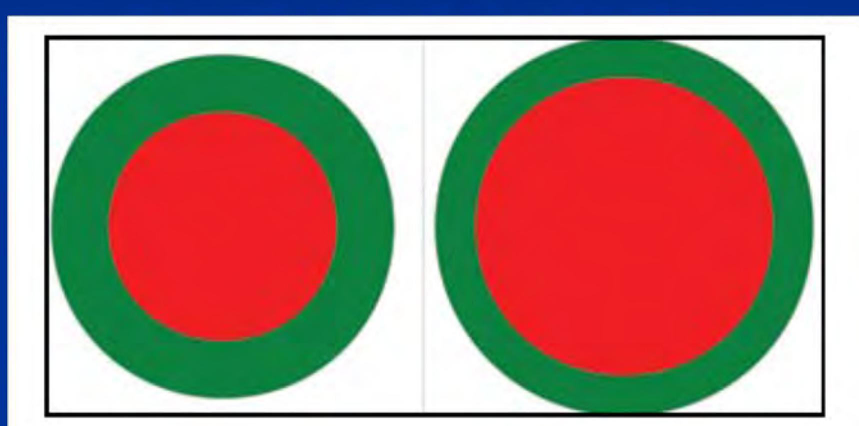
- Change in decay amount over time
- Stability of Barrier zone and Reaction zone

- Increasing trunk diameter
- Amount of sound wood remains static
- Tree becomes more stable



$$MR = pi * \frac{D4-d4}{32 * D}$$

Same Load Carrying Capacity
-Amount of Sound Wood Decreases
-Trunk Diameter Increases



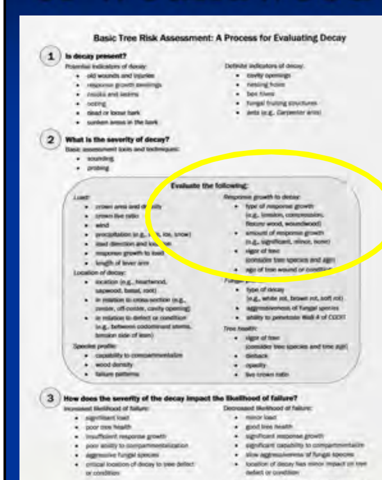
Rinn 2010

Biology Trumps Biomechanics Tipping Point

Biology Trumps Biomechanics Tipping Point

- We need to know
- **Change in amount of sound wood relative to change in diameter**

Decay Assessment-Presence/Absence of Woundwood Response



Basic Tree Risk Assessment: A Process for Evaluating Decay

1 Is decay present?

Potential indicators of decay:
- old wounds and injuries
- response growth swellings
- cracks and seams
- oozing
- dead or loose bark
- sunken areas in the bark

Definite indicators of decay:
- cavity openings
- nesting holes
- bee hives
- fungal fruiting structures
- ants (e.g., Carpenter ants)

2 What is the severity of decay?

Basic assessment tools and techniques:
- sounding
- probing

Evaluate the following:

Load:
- crown area and density
- crown live ratio
- wind
- precipitation (e.g., rain, ice, snow)
- load direction and location
- response growth to load
- length of lever arm

Location of decay:
- location (e.g., heartwood, sapwood, basal, root)
- in relation to cross-section (e.g., center, off-center, cavity opening)
- in relation to defect or condition (e.g., between codominant stems, tension side of lean)

Species profile:
- capability to compartmentalize
- wood density
- failure patterns

Response growth to decay:
- type of response growth (e.g., tension, compression, flexure wood, woundwood)
- amount of response growth (e.g., significant, minor, none)
- vigor of tree (consider tree species and age)
- age of tree wound or condition

Fungal profile:
- type of decay (e.g., white rot, brown rot, soft rot)
- aggressiveness of fungal species
- ability to penetrate Wall 4 of CODIT

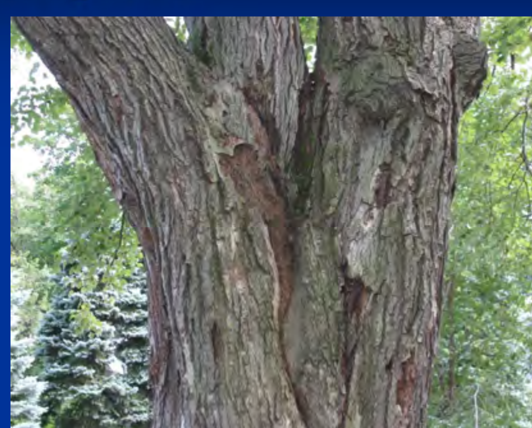
Tree health:
- vigor of tree (consider tree species and tree age)
- dieback
- opacity
- live crown ratio

3 How does the severity of the decay impact the likelihood of failure?

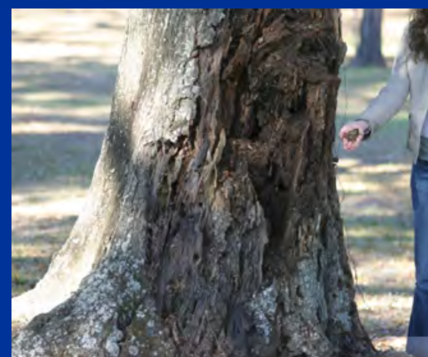
Increased likelihood of failure:
- significant load
- poor tree health
- insufficient response growth
- poor ability to compartmentalization
- aggressive fungal species
- critical location of decay to tree defect or condition

Decreased likelihood of failure:
- minor load
- good tree health
- significant response growth
- significant capability to compartmentalize
- slow aggressiveness of fungal species
- location of decay has minor impact on tree defect or condition

Source: Christopher J. Luley, Ph.D., Urban Forestry LLC



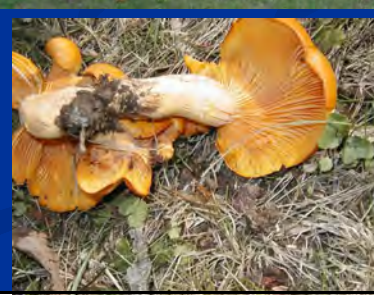
Diagnostics
Absence of WW

Southern Red Oak
Armillaria sp.


Fungal Identification Matters

- Type of decay
- Location of decay
- How it interacts with barrier zone
- Future potential decay progression
- DNA identification of fungi decayed wood
  - Vetdna.com



Molecular Diagnostics vetdna.com $18 per sample


HORTICULTURE SUBMISSION FORM

Owner Name:
Sample ID:
Species:
Date:

Specimen Source (Please Circle)
Swab Leaf/Needle Conk/Mushroom Petiole
Twig Branch Trunk Bore Root Flower

ACCOUNT: Acct # / Name / Address / City / State/ZIP / Phone# / Email / Fax / Text

PAYMENT: Check Enclosed Amount
Credit Card
AMEX Discover Master Card Visa On File
Exp. Date: ___/___
Name On Card
Credit Card Number

DNA TESTS $18.00 each

- Armillaria Ssp
- Ash Yellows (Ca. P. fraxini)
- Bacterial Leaf Scorch (Xylella fastidiosa)
- Bondarzewia berkeleyi
- Botrytis cinerea
- Ceratocystis Ssp
- Cotton Root Rot (Phymatotrichopsis omnivora)
- Dothistroma pini (Dothistroma Needle Blight)
- Dothistroma septosporum (Red Band Needle Blight)
- Dutch Elm Disease (O. ulmi, O. novo-ulmi)
- Elm Yellows (Ca. P. ulmi)
- Emerald Ash Borer (Agrilus planipennis)
- Fire Blight (Erwinia amylovora)
- Fusarium Ssp
- Ganoderma Ssp
- Ganoderma applanatum
- Ganoderma lucidum
- Ganoderma zonatum
- Kretzschmaria deusta (Brittle Cinder Fungus)
- Laetiporus sulphureus
- Oak Wilt (Ceratocystis fagacearum)
- Phaeolus schweinitzii
- Pholiota Ssp
- Phytophthora Ssp
- Phytophthora palmivora
- Phytophthora ramorum
- Phytoplasma Ssp
- Pinewood Nematode (B. xylophilus)
- Pleurotus Ssp
- Pythium Ssp
- Southern Pine Beetle (Dendroctonus frontalis)
- Sparassis spathulata
- Thousand Canker Disease (Geosmithia morbida)

RNA TESTS $25.00 each

- Rose Rosette Virus
- Tobacco Ringspot Virus

PANEL TESTS

- Pine Needle Blight Tri-plex $45.00

- Test wood shavings samples or fruiting structures
- Results "immediately"

DNA testing of wood or conk

- Armillaria ssp. (all species)
- Armillaria gallica
- Armillaria mellea
- Armillaria ostoyae
- Armillaria tabescens
- Bacterial Leaf Scorch (X. fastidiosa)
- Bondarzewia berkeleyi
- Ceratocystis ssp.
- Dothistroma pini
- Dothistroma septosporum
- Dutch Elm Disease (O. ulmi/O. novo-ulmi)
- Elm Yellows (Ca. Phytoplasma ulmi)
- Emerald Ash Borer (Agrilus planipennis)
- Fire Blight (Erwinia amylovora)
- Ganoderma applanatum
- Ganoderma lucidum
- Ganoderma zonatum
- Grifola frondosa
- Kretzschmaria deusta
- Laetiporus sulphureus
- Lecanosticta acicola
- Oak Wilt (C. fagacearum)
- Phaeolus schweinitzii
- Pholiota ssp. (all species)
- Phytophthora ssp. (all species)
- Phytophthora palmivora
- Phytophthora ramorum
- Phytoplasma ssp. (all species)
- Pinewood Nematode (B. xylophilus)
- Pleurotus ssp.
- Pythium genus (all species)
- Rose Rosette Virus
- Sparassis spathulata
- Thousand Canker Disease (Geosmithia morbida)
- Verticillium genus (all species)
- Verticillium albo-atrum
- Verticillium dahlia

Decay Fungi Mode of Action

- Dead wood only (Obligate Saprophytes)
  - Large areas due to wounding or branch death
- Anatomical deadwood (Obligate Saprophytes)
  - Heartwood primarily
- Living sapwood (Facultative Pathogens)
  - Break Barrier zones and Reaction zones
- Cambium killers and Sapwood decayers (Strong Facultative Pathogens)

- Large number of fungi
- Very small number of fungi

Terms

- **Obligate saprophyte-** can only live on dead tissues
  - Dead tissues may be in a living tree
- **Facultative parasite or pathogen** – can infect and live on live and dead tissues
- Obligate parasite- must have living host

True Heart Rots
Obligate Saprophytes
Cannot Breach Wall 4
Perenniporia fraxinophila

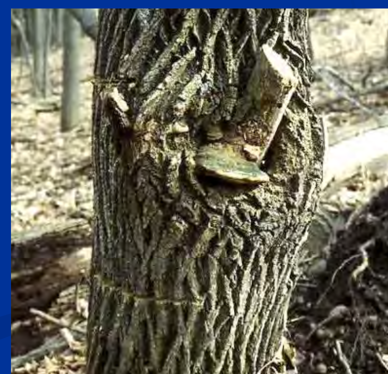


Table 1.—Occurrence of fungi causing decay in living oaks in the central hardwood region, by tree species and type of rot

Fungus species	Identified infections: Scarlet oak	Black oak	White oak	Chestnut oak	Total	Frequency of infection
	No.	No.	No.	No.	No.	Percent
WHITE ROT						
Poria andersonii (Ell. & Ev.) Neuman	12	56	36	13	117	16.36
Stereum frustulatum (Pers. ex Fr.) Fckl.	54	32	7	6	99	13.85
Stereum gausapatum (Fr.) Fr.	28	28	10	6	72	10.07
Polyporus compactus Overh.	15	37	5	5	62	8.67
Unknown "II"	37	2	8	2	49	6.85
Irpex mollis Berk. & Curt.	2	26	13	7	48	6.71
Hericium spp.	4	14	24	3	45	6.29
Polyporus obtusus Berk.	2	3	8	2	15	2.10
Armillaria mellea (Fr.) Quél.	2	3	4	3	12	1.68
Merulius tremellosus Schrad. ex Fr.	2	3	2	3	10	1.40
Hymenochaete rubiginosa Dicks. ex Lév.	8	1	—	—	9	1.26
Polyporus dryophilus Berk.	4	—	2	3	9	1.26
Polyporus versicolor L. ex Fr.	3	3	2	—	8	1.12
Stereum complicatum (Fr.) Fr.	—	3	2	1	6	.84
Polyporus frondosus Dicks. ex Fr.	3	—	2	—	5	.70
Polyporus adustus Willd. ex Fr.	—	2	—	2	4	.56
Poria mutans Pk.	3	—	—	—	3	.42
Pleurotus ostreatus (Jacq. ex Fr.) Kumm.	2	—	—	—	2	.28
Stereum subpileatum Berk. & Curt.	1	1	—	—	2	.28
Rigidoporus citreus (Pers. ex Fr.) Domk.	—	—	—	2	2	.28
Corticium galactinum (Fr.) Burt	—	1	—	—	1	.14
Polyporus fissilis Berk. & Curt.	—	—	1	—	1	.14
Steccherinum setulosum (Berk. & Curt.) Miller	—	1	—	—	1	.14
Total	182	216	126	58	582	81.40

Decay May Produce No Biological Health Symptoms

Heart Rot Fungi-
Some are Weak Facultative Pathogens

- Usually limited to heartwood
- Dead sapwood
- Gain entrance through heartwood wounds
- May weakly attack living sapwood
  - Host interactions

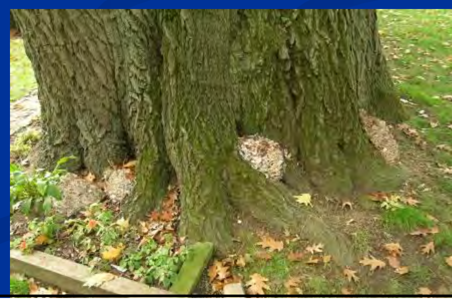



TABLE 1. Mean vertical extent of decay, average yearly extent, and percent of cross-sectional area decayed at the point of inoculation in four northern hardwoods five years after artificial inoculation with common heartrot fungi.

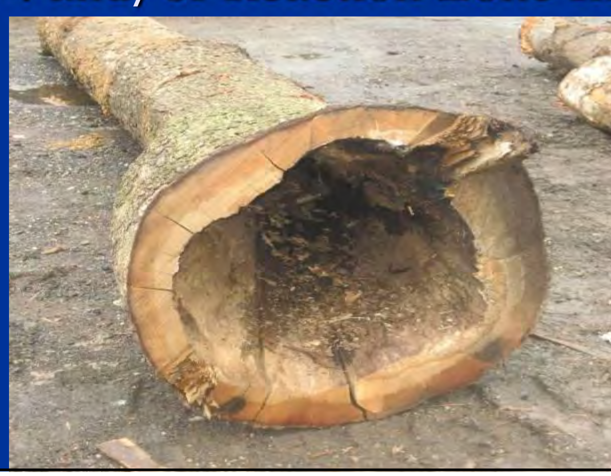
Fungus, host and source[1]	Mean vertical extent of decay in feet[2]		Average yearly extent in feet	Decay at point of inoculation in percent of cross-sectional area
	Down	Up		
Fomes igniarius in bigtooth aspen	3.6 (3.3-4.0)	5.9 (5.5-6.6)	1.90	58.3
Fomes applanatus in American beech	2.6 (1.6-3.5)	3.0 (2.4-3.5)	1.12	57.0
Fomes igniarius in American beech	2.4 (1.6-2.8)	2.4 (1.3-3.3)	0.96	22.2
Polyporus glomeratus in sugar maple	1.4 (1.3-1.6)	1.4 (1.3-1.6)	0.56	45.5
Polyporus glomeratus in American beech	0.4 (0.2-0.5)	0.6 (0.2-0.8)	0.20	13.1
Poria obliqua in yellow birch	0.3 (0.1-0.4)	0.4 (0.1-0.6)	0.14	12.6
Fomes igniarius in sugar maple	0.3 (0.1-0.4)	0.3 (0.1-0.5)	0.12	13.3

[1]Scientific names of the hosts appear in the text and the sources of fungal inoculum are from the same host into which inoculations were made.
[2]Means are based on 5 trees; ranges are included in parentheses.

Obligate Saprophytes Living Trees Decaying heartwood/dead sapwood

Polyporus squamosus?

No Worries as Long as Tree Growth/Health is Maintained Wound Closure Continues Wall 4 and/or Reaction Zone Intact



Mode of Action

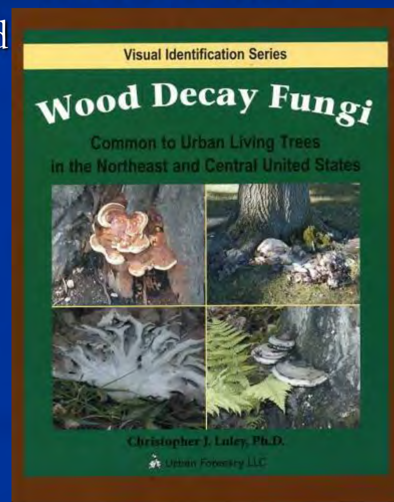
- **Facultative Pathogens**
  -attack both dead and living tissues
  - Weak
  - Strong

Facultative Pathogens
Sapwood Decayers
Establish on dead sapwood
Can attack living bark/wood

- Smaller group
- *Schizophyllum commune*
- *Cerrena unicolor*
- *Trametes versicolor*

Facultative Pathogens-Strong Heart Rot and Sapwood Rot Breach Wall 4 and Reaction Zones

- Can attack healthy sapwood
- More aggressive decayers
- Small group of fungi
  - ***Kretzschmaria deusta***
  - ***Ganoderma lucidum***
  - ***Armillaria mellea***
  - ***Ganoderma applanatum***
- Canker Rots



Ganoderma lucidum

Ganoderma lucidum
aka Reishi
Cambium killer!


Ustulina

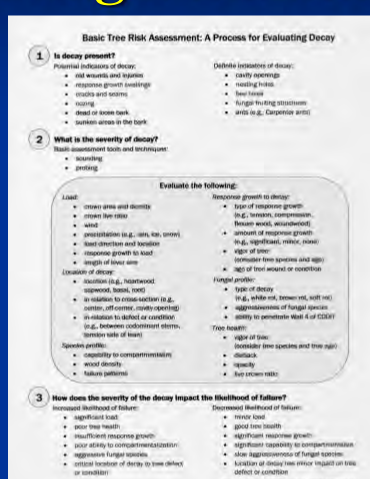
(Hypoxylon deustum)

Kretzschmaria deusta

Burnt Crust Fungus

Will kill Woundwood, penetrate Barrier zones and Reaction Zones

Fungal Identification Matters



Basic Tree Risk Assessment: A Process for Evaluating Decay

1 Is decay present?

Potential indicators of decay:
- old wounds and injuries
- response growth swellings
- cracks and seams
- oozing
- dead or loose bark
- sunken areas in the bark

Definite indicators of decay:
- cavity openings
- nesting holes
- bee hives
- fungal fruiting structures
- ants (e.g., Carpenter ants)

2 What is the severity of decay?

Basic assessment tools and techniques:
- sounding
- probing

Evaluate the following:

Load:
- crown area and density
- crown live ratio
- wind
- precipitation (e.g., rain, ice, snow)
- load direction and location
- response growth to load
- length of lever arm

Location of decay:
- location (e.g., heartwood, sapwood, basal, root)
- in relation to cross-section (e.g., center, off-center, cavity opening)
- in relation to defect or condition (e.g., between codominant stems, tension side of lean)

Species profile:
- capability to compartmentalize
- wood density
- failure patterns

Response growth to decay:
- type of response growth (e.g., tension, compression, flexure wood, woundwood)
- amount of response growth (e.g., significant, minor, none)
- vigor of tree (consider tree species and age)
- age of tree wound or condition

Fungal profile:
- type of decay (e.g., white rot, brown rot, soft rot)
- aggressiveness of fungal species
- ability to penetrate Wall 4 of CODIT

Tree health:
- vigor of tree (consider tree species and tree age)
- dieback
- opacity
- live crown ratio

3 How does the severity of the decay impact the likelihood of failure?

Increased likelihood of failure:
- significant load
- poor tree health
- insufficient response growth
- poor ability to compartmentalization
- aggressive fungal species
- critical location of decay to tree defect or condition

Decreased likelihood of failure:
- minor load
- good tree health
- significant response growth
- significant capability to compartmentalize
- slow aggressiveness of fungal species
- location of decay has minor impact on tree defect or condition

Source: Christopher J. Luley Ph.D., Urban Forestry LLC