Decay Fungi Associated with Oaks and Other Hardwoods in the Western United States.

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An assessment of the presence and extent of the wood decay process should be part of any hazard tree analysis. Identification of the fungi responsible for decay improves both the prediction of the consequences of wood decay and the prescription of management options including tree pruning or removal. Until the outbreak of Sudden Oak Death (SOD), foresters in the Pacific Northwest emphasized conifer diseases and decay with little attention to hardwood pathology. The SOD outbreak has drawn attention to hardwood tree species, particularly for the urban forest in which native or introduced hardwoods may predominate. Consequently, the hazard tree specialist needs a working knowledge of the fungi associated with hardwood decay. We present here some of the common fungi responsible for decay of hardwoods, particularly of oak, tanoak *(Lithocarpus densiflorus*), and chinquapin (*Castanopsis* spp.) in the West.

Identification of wood decay fungi is made a little easier through grouping wood decay fungi by habitat, spatial position, and the appearance of the decayed wood (Tainter and Baker, 1996). Some wood decay fungi are saprotrophic and attack wood in service or felled logs, slash, or snags (Toupin et al., 2008). Pathogenic wood decay fungi are sometimes placed in convenient categories such as heartrot fungi (that can decay heartwood in living trees despite tree-produced protective chemicals and low oxygen conditions (Highley and Kirk, 1979), saprot fungi (that decay sapwood exposed by more-or-less recent mechanical injury), and primary pathogens that directly kill living sapwood cells in advance of infection (canker rot and many root rot fungi) (Shortle et al., 1996).

Wood decay fungi are also categorized by the appearance of decayed wood. White-rot fungi degrade the lignin, cellulose and hemicellulose of wood, leaving behind a white or off-white residue. Brown- rot fungi degrade the cellulose and hemicellulose in the wood cell wall but do not significantly degrade the lignin. They leave behind a brown residue, composed largely of lignin, that becomes part of soil humus and resists further degradation. This brown-rot residue is an important component of the carbon sequestered in forest soil. White-rot fungi frequently decay hardwoods, and brown-rot fungi usually colonize conifers, but many exceptions occur. The decayed wood within the tree can take different forms, including “stringy rot,” “spongy rot,” “pocket rot,” “cubical rot,” and “laminated rot.” Each of these decay types has different physical properties that affect the amount of strength remaining in the wood. In brown-rot decay, large amounts of strength loss occur early in the decay process due to the rapid depolymerization of cellulose (Cowling, 1961).

Many decay fungi can be categorized using the above static criteria. However, the great advance in understanding of the biology of wood decay in living trees involves the compartmentalization process (Shigo, 1984), a foundation concept in forest pathology (Manion, 2003). Prior to the description of the compartmentalization process, heartrot was considered to result from the direct infection of dead heartwood exposed by injury. In the compartmentalization concept, heartrot generally begins with the infection of sapwood by a succession of fungi. The spread of those fungi is resisted through the constitutive and induced boundaries and barriers of compartmentalization (Smith 2006). As the vascular cambium continues to produce new xylem and healthy sapwood continues to be converted into heartwood, the infection appears to become more-or-less centered in the middle of the tree.

More important than questions of what constitutes a true "heartrot" fungus, or whether trees that do not produce heartwood can have heartrot, or whether decay of heartwood in a living tree is the product of a saprophyte or a pathogen, is to recognize that trees actively respond to injury and colonization by decay fungi. Infections in a young tree can produce a cascade of processes that result in long-standing decay and cavities in large, mature individuals.
The types of decay, morphological features of the fruiting body, and a short discussion about the impact on hazard tree analysis are presented for some of the major decay fungi associated with oaks and other hardwoods in the Western United States.

I. Pathogenic fungi

Abortiporus biennis – annual, sessile or sometimes with a lateral or central stalk, sometimes distorted with pores covering the entire fruiting body. Upper surface, when it is present, is white to pale brown, azonate to slightly zonate, hairy or nearly smooth. Spore-bearing surface poroid, pores round to angular, 2 – 4 per mm, white bruising red. A white-rot of dead hardwoods, a white trunk-rot of living hardwoods, sometimes fruiting on the ground from subterranean roots (Binion et al., 2006

Armillaria mellea –Although the traditional concept of *A. mellea* has been split up into 10 biological species in North America, the name is still valid for the root- rot fungus present on hardwoods and some conifers in California but not associated with hardwoods in the Pacific Northwest. Fruiting bodies are gilled mushrooms, produced in clusters of 8 – 10 but sometimes 30 or more. Cap is honey-colored with a smooth surface, 3 – 13 cm wide. Gills are attached to the stalk ("stipe"). Stipe tapers at the

base and usually has a persistent ring, or "annulus," at the upper portion. Black rhizomorphs form on the surface of colonized roots and under the bark of infected trees (Burdsall and Volk, 1993). Mycelial fans may also form beneath the bark of diseased roots and the root crown. Causes serious white-rot root disease, especially in urban trees stressed by drought or other disturbances. Wood initially appears water-soaked, then becomes light colored and spongy with more advanced decay (Swiecki and Bernhardt, 2006).

***Armillaria solidipes* (syn. *A. ostoyae*).** Although usually associated with a devastating white-rot root disease of conifers, *A. solidipes* is also associated with hardwoods in the West. The fruiting body is a gilled mushroom, found in large clusters, with a brownish ring ("annulus"). The base of the stipe is frequently pointed. The cap is brown, covered with dark scales, and can be very large – up to 1 foot in diameter (Burdsall and Volk, 1993, Burdall and Volk,2008, Volk 2010).

Fomes fomentarius – "Tinder conk." Perennial, hard, woody, horse hoof-shaped conk with prominent zones and furrows, broadly attached to substrate. Upper surface usually pale to dark grey or brown. Spore-bearing surface poroid, concave, tan- to cream-colored when young becoming ochraceous to pale brown with age. Pores round, 2 – 4 per mm. Solitary or in groups on living trees, stumps and logs. Causes a white spongy mottled heartrot of living trees; continues to fruit on dead stumps and logs (Binion et al., 2008; Gilbertson and Ryvarden, 1986). Decay first appears as a light brown discoloration, the wood remaining quite firm. Wood with advanced decay is yellow-white, soft and spongy, and frequently contains brown to black zone lines. Small radial cracks filled with yellow fungal mycelium develop, giving the decay a mottled appearance (Allen et al., 1996). Most common on birch.

Ganoderma applanatum – "Artist's Conk." Fruiting body perennial, 5 – 52 cm wide or even larger, convex, hoof-shaped to fan-shaped, stalkless. Upper surface hard, concentrically zonate and furrowed, gray to brown to grayish brown. Spore-bearing surface poroid, white at first becoming off white to dingy yellow with age, staining brown upon bruising (which allows it to be used by artists as a canvas). Pores very small, 4 – 6 per mm. Solitary or in overlapping clusters on stumps, logs, or wounds of living trees. Common. (Binion et al., 2008). Forms a mottled white-rot of roots, root crown and trunks. In the East, the presence of conks can be cause for immediate removal since they are often associated with advanced decay and potential failure (Luley, 2005). In the West, conks are not as common on oak but more frequently observed on big leaf maple (*Acer macrophyllum*) and bay laurel (*Laurus nobilis*) where they are not associated with advanced decay (Shaw, 2010). Oaks with fruiting bodies are often extensively decayed and may have an elevated failure rate. The fungus often enters tree through wounds in exposed roots and base of tree. Decay commonly extends 1 – 2 m above and below the fruiting body. Decline and mortality more pronounced during periods of environmental stress (Swiecki and Bernhardt, 2006). *Ganoderma brownii*, which is more hoof shaped, is a closely related species that occupies a similar niche in California

Ganoderma lucidum – "Reishi," "Varnish Conk." Found in California but not the Rocky Mountains or Pacific Northwest (Swiecki and Bernhardt, 2006). Fruiting body annual, 2.5 – 3.5 cm wide, semi-circular to fan-shaped or kidney-shaped, surface with concentric zones and furrows, shiny, dark red, reddish-brown to orange-brown becoming ochre or yellow toward the margin. Stalk lateral, 2.5 – 10 cm long and 0.5 – 4 cm thick. Spore-bearing surface poroid, off-white to yellow initially but becoming brown with age or upon bruising. Pores small, 4 – 7 per mm. (Binion et al., 2008). Causes white root-rot and butt- rot of living native hardwoods and exotic ornamental hardwood trees and shrubs. Fruiting bodies develop at or near the ground line (Gilbertson and Ryvarden, 1986). In California, fruiting bodies generally do not form until there is extensive decay with an elevated risk of failure (Swiecki and Bernhardt, 2006). This is in contrast to the Eastern U.S. and Midwest where the presence of fruiting bodies alone is usually not reason for tree removal (Luley, 2005). The closely related varnish conks, *Ganoderma tsugae* and *G. oregonense*, are found on conifers.

Grifola frondosa – "Maitake," "Hen of the Woods," "Sheep's Head." Fruiting body composed of compound clusters up to 30 cm across made up of individual fan-shaped to club-shaped lobes developing from a lateral, thick, branched stalk. Upper surface ochre-brown to grayish-brown or blackish-brown. Spore-bearing surface poroid, white to off-white, pores round to angular, 1 – 3 per mm. Occurs in small to massive clusters at the base of living oak trees or stumps. Usually considered a weak pathogen and may occur at the base of the same tree for many years (Binion et al., 2008). It causes a white-rot and butt-rot, predominantly of oak but also on other hardwoods and conifers. Very rare in the Pacific Northwest (Gilbertson and Ryvarden, 1986) but may escape from cultivation. Often found on oaks that have no other symptoms of decay. Not a cause for immediate removal (Luley, 2005).

Hericium erinaceus – (Hedgehog Fungus, Bear's Head Tooth or Pom Pom Mushroom). Fruiting body annual, solitary, 10 – 20 cm wide. Spore-bearing surface consists of many closely-packed, slender, icicle-like teeth 2 – 5 cm long. Teeth are white when young becoming yellow, brownish, or sometimes reddish with age. Young fruiting bodies are edible although may cause allergic reactions in some individuals. Causes a white pocket rot of living trees, associated with wounds. Decayed tissue initially spongy and eventually degrades to leave a large cavity (Swiecki and Bernhardt, 2006).

Inonotus andersonii – A resupinate (flat) polypore that forms sheet-like fruiting bodies on dead wood underneath the bark and sometimes between outer layers of the sapwood. Fruiting bodies initially cinnamon brown but become black with age, usually 0.3 – 1.0 m long. Pores circular to angular, 1 – 6 per mm. Spore deposits on inner bark initially bright sulphur yellow, becoming brown with time. Very common pathogen on living oaks causing white-rot of heartwood and strips of decay in the sapwood. Advanced decay appears bleached, is very light in weight, and crumbles easily. Also forms cankers and kills the cambium resulting in dieback, failure and mortality (Swiecki and Bernhardt, 2006). There are dozens of other resupinate polypores that are not easily distinguished without a microscope. Some of these species are pathogenic, but most are saprotrophic.

Inonotus hispidus – "Shaggy Polypore." Fruiting body broadly attached, usually solitary, up to 10 X 15 cm wide by 8 cm deep. Top, including the edge, is reddish orange, becoming reddish brown to nearly black with age, no zonations. Many coarse hairs when young ("hispid"). Pore surface yellow-brown becoming dark brown with age. Pores angular, 1 – 3 per mm, becoming eroded and uneven. Causes a white heartrot of living oaks (Binion et al., 2008). Capable of killing sapwood in living trees and is commonly associated with trunk cankers on oaks. In Arizona, it is a major decay fungus of Arizona black walnut (*Juglans major*) (Gilbertson and Ryvarden, 1986).

Inonotus dryadeus (syn. *Pseudoinonotus dryadeus)* – "Weeping Conk." Fruiting bodies annual but persistent, developing at the base of trunk or on roots below the soil surface, variable in size but can be very large (up to 75 cm wide), initially soft but becomes dried and cracked with age. Top surface of fresh fruiting bodies are yellowish to brown, blackening with age, and may have many droplets of amber-colored exudates. Lower surface buff with fine circular to angular pores, 4 – 6 per mm. Causes a slowly developing white-rot root disease and butt-rot with most of decay concentrated in larger roots. Affected trees may have significant amounts of root decay and an elevated risk of windthrow (Luley, 2005; Swiecki and Bernhardt, 2006).

Inonotus dryophilus – Very similar to *Inonotus hispidus* in appearance except lacking the hispid (hairy) upper surface (Binion et al., 2008). Pore surface initially buff becoming dark reddish brown, rough, pores angular, 1 – 3 per mm with thin border tissue that breaks up so pores become eroded and irregular with age. Causes a white-rot of heartwood in the trunk of living oaks and also decays strips or sections of sapwood, forming elongate cankers and killing the cambium. Brown mycelium accumulates in the decayed wood in advanced decay (Gilbertson and Ryvarden, 1986). Fruiting occurs well above the ground line (Luley, 2005). One of the most serious pathogens of living oaks in California associated with decline, failure, and mortality (Swiecki and Bernhardt, 2006).

Laetiporus gilbertsonii –Fruiting bodies shelving, up to 20 cm wide, with a lateral narrow or wide stalk ("stipe") or sessile. Upper surface pale salmon-orange or pale pinkish-orange to tan or light brown in age, sometimes nearly white. Pore surface lemon-yellow to pale lemon-yellow. Pores initially circular becoming more angular with age, 2 – 4 per mm, present along stipe to attachment point. Causes a brown-rot of *Quercus* and *Eucalyptus* species in living trees or dead trunks and logs (Burdsall and Banik, 2001). The decay is a cubical heartrot that may lead to failure in the main stem or butt. Decay may progress into major roots. The presence of *Laetiporus* fruiting bodies is often an indicator of extensive decay but some trees may still be sound enough to retain and test periodically (Luley, 2005). *Laetiporus conifericola* is similar but grows only on conifers.

Phellinus everhartii – Fruiting body is perennial, stalkless, and hoof-shaped, 6 X 13 X 8 cm. Upper surface of conk is dark brown to black, velvety when young but becoming smooth and eroded with age. The spore bearing surface is poroid, with a velvety appearance, dark chocolate brown, pores circular to angular, 5 -6 per mm. Causes a white-heart rot of living oak. (Binion et al, 2006; Gilbertson and Ryvarden, 1987). There are several other similar species that are difficult to distinguish without a microscope.

Phellinus gilvus– "Mustard Yellow Polypore." Fruiting body annual to perennial, sessile or slightly effused-reflexed, solitary or shelving in large numbers. Upper surface is dark yellow-brown to rusty brown, velvet when young, becoming smooth with age, tapering to a sharp margin. Spore-bearing surface poroid, reddish brown to dark purple brown, pores circular to angular, 1 – 5 per/mm (Binion et al, 2006). Can cause a white-rot of heartwood of living oaks and a uniform white rot of dead wood (Gilbertson and Ryvarden, 1987).

II. Saprotrophs

Armillaria gallica – "The Humongous Fungus." *Armillaria gallica* is found on hardwoods in the West, but it is relatively rare. It is a white rot saprotroph and is usually found at the base or on the surface of dead logs and stumps or growing from buried roots. The fruiting bodies are gilled mushrooms, smaller than other species of *Armillaria*, found in small clumps or solitary. The caps are tan to pinkish brown and distinctly hairy. The partial veil that forms a ring ("annulus") on the stipe is cobwebby and erodes with age, leaving spider-like remnants on the stipe. The base is usually swollen and often stains yellow when bruised and may be attached to black rhizomorphs (Burdsall and Banik, 1993). In the Midwest, it forms huge clonal colonies. One colony was shown to be spread over a 15 hectare (37 acre) area and may be one of the oldest living organisms on the planet (Smith et al., 1992**).**

Armillaria nabsnona – *Armillaria nabsnona* is found on many hardwoods in western North America, including oak, but most commonly on *Alnus* species. Macroscopic characters that may be used to distinguish *A.nabsnona* from other North American species of *Armillaria* include a more orange coloration when fresh and a narrower stipe in comparison to the size of the cap. The stipe is darker than other *Armillaria* species, especially when dried. There are no scales, but small black hairs may be present on the surface of the pileus, a similar situation to that found in *A. mellea*. It is often associated with dead wood in riparian zones and causes a white rot (Volk et al., 1996).

Bjerkandera adusta – "Smoky Polypore." Fruiting body effused-reflexed to sessile, shelf-like, frequently in large numbers, frequently coalescing to form larger fruiting bodies or uniting to form large sheets on the underside of logs. Upper surface is pale yellow-white to pale creamy-buff, becoming grayish-white with age. Smooth to finely fuzzy. Pore surface pale gray to dark gray, sometimes with a brown tint. Pores 5 – 7 per mm, circular, becoming angular with age, gray. White-rot of fallen wood or standing snags (Binion et al, 2006). Most common on aspen,

Cerrena unicolor – "Mossy Maze Polypore." Fruiting body annual, sessile or effused-reflexed, semicircular, often shelving and coalescing laterally. Upper surface gray to brownish gray, very hairy-fuzzy, usually green from growth of associated algae, zonate to somewhat zonate. Spore-bearing surface poroid but with maze-like pores, pale ivory to gray, 3 – 4 pores per mm. (Binion et al., 2006) It is a symbiont of the wood wasp *Tremex columba* (Gilbertson and Ryvarden, 1986). An aggressive white saprot than can decay a large portion of the trunk and can also kill the cambium as a canker rot. Infected stems are subject to breakage. A common invader after damage from ice storms and other wounds (Luley, 2005).

Daedalea quercina – "Thick Maze Polypore." Fruiting bodies annual or perennial, broadly attached, bracket-like, 5 – 15 cm wide, upper surface convex to flat, uneven, white to pale brown or grayish brown. Pore surface irregular, pores 1 mm or wider in diameter, walls between pores thick, pores usually maze-like to nearly gill-like, white to light brown, at times with pinkish tones. Solitary or in small groups. Rare west of Mississippi River (Binion et al, 2006). Slowly progressing brown-rot in butt and trunk that progresses to form hollow cavities. Usually not a reason for immediate removal but affected trees should be monitored (Luley, 2005).

Daedaelopsis confragosa – "Thin-walled Maze Flat Polypore." Fruiting bodies annual but persistent, bracket-like, 2.5 – 15 cm wide, upper surface convex to flat with a thin, sharp margin, usually zonate. May have matted hair on surface or be smooth. Gray to brown or reddish brown. Pore surface poroid to maze-like or gill-like, white to brownish, bruising pinkish. Extremely variable in appearance. White-rot on dead wood. On oak and many other hardwoods. (Binion et al., 2006) Infrequent in the West but more common in the Northwest (Gilbertson and Ryvarden, 1986).

Irpex lacteus – "Milk-white Toothed Polypore." Fruiting bodies annual, broadly effused to effused-reflexed, sessile. Often fruiting bodies fuse laterally to make large sheets that totally cover broken or dead branches. Upper surface white to pale cream-color, hairy, sometimes zonate. Pore surface appears spiny because of erosion and splitting of pores, white to pale cream-colored. Pores initially angular, 2-3 per mm. White-rot on fallen branches and dead branches still attached to the tree. (Binion et al, 2008).

Ischnoderma resinosum – "Resinous Polypore," Fruiting body annual, fan-shaped to semicircular, up to 25 cm wide. Margin rounded. Upper surface velvet or hairy becoming smooth with age, often radially wrinkled, zonate with dark brown to rusty brown wrinkles. Pores creamy white to ochraceous, bruising brown, circular to angular, 4 – 6 per mm. Young fruiting bodies exude amber-colored droplets.

Fruiting bodies solitary or in groups on logs, stumps, and standing trees (Binion, et al, 2008). The decay is a white-rot that is yellowish and stringy to spongy with a strong odor of anise (Gilbertson and Ryvarden, 1986).

Lenzites betulina – "Multicolor Gill Polypore," "Gilled Polypore." Fruiting body annual but persistent over winter, kidney-, fan-shaped or semicircular, 3 – 10 cm wide. Upper surface velvety to hairy with distinct multi-colored zones or grooves in shades of pink, tan, gray, yellow, orange or brown; older specimens may be green from algal associate. Pores are gill-like, radiating from point of attachment. Often found in overlapping groups or shelving on dead branches, logs and stumps (Binion etal., 2008). Absent or rare in the Rocky Mountains but present in the Pacific Northwest. Often on *Betula* but also found on many other hardwoods and conifers (Gilbertson and Ryvarden, 1986).

Polyporus species: – The genus *Polyporus* is a large group of poroid fungi that can be recognized by their central to lateral stipe. Most species have a light to deep brown upper surface and are tough when fresh and woody when dried. Some of the common species are: *P.* arcularius (shown at right), a smallish polypore (up to 4 cm wide) with a central stipe and radially arranged hexagonal pores; *P. badius* (syn. *Royoporus badius*), a fairly large but thin polypore (up to 15 cm broad) with a central or lateral stipe that is black and minutely hairy at its base; and *P. brumalis*, which is of medium size (up to 8 cm wide) with a central or lateral stipe and angular pores. All cause a white-rot of woody debris and dead trees (Binion, 2008; Gilbertson and Ryvarden, 1987).

Stereum species – Species of *Stereum* are easily recognized by their relatively thin fruiting bodies that are often fan-shaped to paddle-shaped and their smooth spore-bearing undersurface that is devoid of pores, gills or other supporting structures. Many resemble other decay fungi and are only recognized as belonging to the genus *Stereum* when the smooth lower surface is observed. *Stereum hirsutum* (shown at right) is effused-reflexed to sessile, has an upper surface that is initially wooly, becoming smooth with age, with concentric zones of orange brown to grayish tan colors, and a smooth brownish spore-bearing surface that bruises yellow when fresh, usually found on logs. *Stereum ochraceoflavum* forms typical shell-shaped fruiting bodies but also saucer-shaped fruiting bodies that may partially or completely surround the sticks on which they grow. The upper surface is buff to tan-brown, indistinctly zoned, and uniformly hairy (Wood, 2010). All *Stereum* species cause a white saprot and are associated with dead trees and woody debris. Several other *Stereum* species grow on conifers, especially *S. sanguinolentum*.

Stereum hirsutum

Trametes *species* – The genus *Trametes* contains many common saprot fungi with broad host and geographical ranges. The group is characterized primarily by microscopic characteristics – the poroid fruiting bodies are formed from three different types of fungal hyphae which give them a characteristically hard, leathery texture. *Trametes versicolor*, the "Turkey Tail Fungus" has a zonate, multicolored upper surface varying from hairy to smooth or velvety in narrow concentric zones. It often forms large clusters of shelves. *Trametes hirsuta* is also zonate but with much more subdued colors, predominantly shades of white, gray and tan with concentric zones of thick and thin woolliness. is velvety to hairy but becomes smooth with age, cream-colored to grayish yellow and only faintly zonate to azonate. All of these fungi are strong white-rotters. (Binion et al., 2008) *Trametes versicolor* can attack and colonize cambium adjacent to dead wood and form cankers. The presence of *Trametes* and

other saprot fungi is an indication that the branch or section of trunk is dead and decayed. Sanitation pruning to remove infected branches is recommended since some of them can infect and colonize healthy tissue (Luley, 2005).

Trametes versicolor

Trametes hirsuta

Trichaptum bifor*me* – "Violet-toothed Polypore." Fruiting bodies annual, sessile or effused-reflexed, solitary or shelving, often coalescing to form large sheets. Upper surface is gray to tan, hairy to smooth, with concentric zones of thick and thin woolliness. Pore surface is purple to pink especially at the margins but becoming brown with age. Pores initially angular, 3 – 5 per mm but eventually eroding and splitting to form teeth. Common on fallen oak debris, logs and stumps (Binion et al., 2008). Forms a white pocket rot of sapwood on dead hardwoods. The wood becomes lacy and fragile with small empty pockets (Gilbertson and Ryvarden, 1987). *Trichaptum abietinus* is similar, but grows on conifers.

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