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Rust-Red Stringy Rot caused by the Indian Paint Fungus

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The true firs (*Abies* spp.) and hemlocks (*Tsuga* spp.) are important trees in western North American forests that can be seriously affected by a decay pathogen, the Indian paint fungus (*Echinodontium tinctorium* [El. & Ev.] Ellis & Everhart). In the interior West, many stands that were historically dominated by ponderosa pines have been converted gradually in part or entirely to fire-intolerant true-fir stands as a result of fire exclusion and past-harvesting practices that routinely involved leaving true firs while removing the more valuable pines and other species. With these shifts toward much larger numbers of susceptible hosts, the Indian paint fungus has become increasingly important.

The Indian paint fungus is responsible for 80% of the decay in old-growth grand and white fir stands in eastern Oregon and Washington and 30% of the decay in advance fir regeneration. Similar levels of decay probably exist in other parts of interior western North America but have not been quantified. In British Columbia, *E. tinctorium* has a wide ecological amplitude but is more common inland than on the coast. In Oregon and Washington, infection, decay, and sporulation levels are higher in the interior wet true fir habitats than in the dry fir habitats.

Besides causing significant loss of commercial wood volume, the decay caused by the Indian paint fungus can severely weaken host-tree boles resulting in hazard or danger trees in developed-recreation sites or along roads and trails. On the positive side, decay caused by the Indian paint fungus and other fungi can (1) contribute to important habitat for cavity-nesting animals in standing live trees and down hollow logs, (2) result in broken stems that increase stand-structural complexity and diversity, and (3) facilitate nutrient cycling and organic-matter development in forest soils.

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Hosts and Distribution

The decay caused by the Indian paint fungus, called rust-red stringy rot, is found in many conifers including white fir, grand fir, Pacific silver fir, noble fir, California red fir, Shasta red fir, subalpine fir, western hemlock, and mountain hemlock. The causal fungus occurs rarely in Engelmann spruce, white spruce, Douglas-fir, and corkbark fir.

Decay is most extensive in white fir, grand fir, red fir, and mountain hemlock in central and eastern Washington and Oregon, southern Oregon and northern California, and northern Idaho and Montana. Severe decay also can occur in western hemlock in interior British Columbia and northern Idaho; grand fir, Pacific silver fir, subalpine fir, and mountain hemlock in British Columbia and northern Washington; and mountain hemlock in Alaska. Little or no decay caused by the Indian paint fungus has been reported in other locations in North America.

Fungus Biology and Conks

The Indian paint fungus belongs to a group of decay fungi that cause true heart rots. True heart-rotting fungi are so named because (1) the typical decay is usually confined to the true heartwood, (2) they consistently produce conks on live trees, (3) they never occur as primary invaders of slash and dead material or cause damage to wood in service, although they may continue to develop in cut logs, and (4) mechanical injuries do not appear to serve as the principal infection courts. Because decay caused by heart-rotting

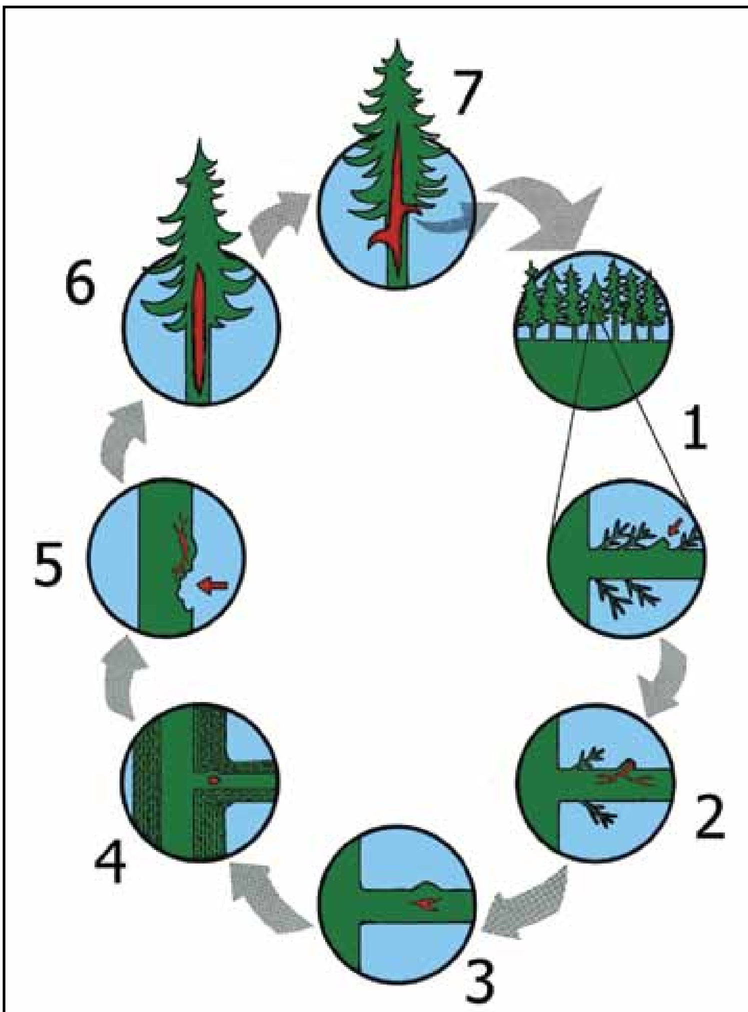

Figure 1. Life cycle of the Indian paint fungus. Numbered stages are explained in the text.

fungi accumulates with tree age, fungi such as the Indian paint fungus tend to be more prominent in older than younger stands.

The life cycle of the Indian paint fungus is illustrated in Figure 1 with the various stages numbered. The most conspicuous sign of the Indian paint fungus is the perennial sporophore or conk (Figure 2). Conks range from an inch to a foot in width. They are woody with black, cracked upper surfaces; gray, spiny or toothed lower surfaces; and reddish-orange interiors (Figure 3). The interior of the conk or context was used by some indigenous people in paint mixes, hence the common name. Conks develop on host-tree boles, usually on the undersides of dead branches. Normally the rust color extends from the decayed heartwood into the cores of infected branches. Branch stubs that contain the rust-colored decay are termed “rusty knots” and can be useful for detecting heart rot, especially in felled trees

Airborne spores are produced by conks throughout the year. Optimal conditions for sporulation and germination, however, occur during the spring and fall when temperatures periodically fall below 40ºF, and mean daily temperatures are 40-65ºF. High levels of humidity are not required for sporulation except at temperatures above 40ºF. It has been estimated that a single 6-inch-wide conk can produce over 100,000,000 spores per week at peak sporulation.

Spores of the Indian paint fungus do not infect wounded tissues or large, old branch stubs as was once thought. Instead, spores infect advance regeneration through small (<2mm diameter) exposed stubs of shade-killed branchlets before the stubs are overgrown (Stage 1 in Figure 1). Branchlet stubs form when dead branchlets break off at their base and expose presumably sterile wood to infection. Suppressed and slowly growing trees heal these branchlet stubs very slowly, thus allowing more time for infection by Indian paint fungus spores. Also, suppressed branches have more shade-killed branchlets and thus produce more branchlet stubs or potential infection courts. Trees or branches that are growing vigorously heal branchlet stubs rather quickly. Therefore, true fir or hemlock stands or stand components that originate from suppressed

Figure 2. Conks of the Indian paint fungus often form at the branch stubs. A - old conk, B - young conk.

Figure 3. Conk interior is bright reddish-orange.

Figure 4. Suppressed true fir understories, such as this one, are more susceptible to infection by the Indian paint fungus.

understories have a much higher infection potential for Indian paint fungus than those that develop from vigorous, unsuppressed regeneration (Figure 4).

After Indian paint fungus spores have germinated and mycelium develops within the infected branch, fungal growth continues until branchlet stubs are overgrown (Stage 2). Infections enter the heartwood of the main branch through the secondary branch traces and become localized in tissues around the pith until conditions are favorable for further development. After stubs are overgrown, the fungus becomes dormant as a resting spore (chlamydospore) that can survive for 50 or more years without causing decay (Stage 3). Branches may contain 20 or more resting spores. Branches with chlamydospores close to the trunk are eventually encased within the trunkwood as bole diameter increases (Stage 4). The frequency of dormant infections increases progressively with increasing branch age after 40 years in western hemlock and probably also mountain hemlock and true firs.

Dormant infections may be activated by mechanical wounds, top breaks, frost cracks, fir engraver attacks, or formation of large branch stubs that allow air access to the trunk interior where the dormant infections are located (Stage 5). Wounds, even if very small ($\geq$9 in^2), within one foot of dormant spores can activate the chlamydospore resulting in fungal growth. Several factors, however, determine the amount of subsequent decay such as tree genetics, tree age, and wound size. The larger the trunk wound, the more likely that one or more dormant infections will be activated and cause decay.

Activated infections first cause elongated areas in the heartwood that are slightly darkened or water-soaked in appearance.

This stage is followed by development of a light brown or yellow color that may become bluish. At this incipient stage of decay, the structural properties of the wood are not visibly altered, although the strength of the wood will already be reduced. Advanced decay, which appears yellow to reddish-yellow to brown with red zone lines and has a fibrous or stringy texture, is the culmination of prolonged fungal growth (Figure 5). Although the fungus causes a brown-stringy decay, it is classified as a white rot fungus since the lignin in the decayed wood is destroyed leaving some of the cellulose in all but the most advanced cases. The decayed wood is unsuitable for pulp. Frequently, advanced decay appears as a ring rot or separation of the wood along annual rings. Once called brown stringy rot, the common name was changed to rust-red stringy rot, which is more descriptive and avoids confusing the causal fungus with generic "brown rots."

Extensive heart-rot columns may occur after several dormant infections become active, cause decay, and subsequently coalesce (Stage 6). In older trees, decay often occupies the entire heartwood and extends into roots and larger branches. During the final stages of decay, the cellulose eventually can be destroyed as well as the lignin, and the stringy mass of decayed wood may completely disintegrate, leaving a hollow in the tree (Figure 6). Hollows are evidence that the decay is compartmentalized in live trees with surrounding rinds of sound wood, but rust-red stringy rot may develop in the newer sound wood if additional bole wounding and spore activation occur.

Conks are formed after extensive advanced decay develops and usually at the interstice between a dead branch stub and the trunk (Stage 7). Spores can be produced by the perennial conks for decades on living trees and for several years on standing dead trees. Also, spores may be produced for at least 10 years from conks on trees that have been felled. Conk survival is poorer on trees bucked into logs than on felled, intact trees. The percentage of conks surviving on moderately to heavily shaded logs is twice that on lightly shaded or exposed logs. The Indian paint fungus has been reported to survive for more than 5 years in naturally infected air-dried blocks of wood.

Estimating Extent of Infection and Decay

Rust-red stringy rot is not confined to any particular part of the tree bole. For standing trees, decay extent and location within the bole are indicated by the location, distribution, and size of conks

Figure 5. Advanced decay is soft, stringy, and brownish to rusty red.

Figure 6. Trees with advanced decay often become hollow as decay is compartmentalized.

Figure 7. Cross-section cuts at log-length intervals in the bole of a white fir containing rust-red stringy rot show the longitudinal extent of the rot column.

(Figure 7). As an example, the decay (cull) rules shown below were developed for rust-red stringy rot in white and Shasta red fir in southwestern Oregon.

These guidelines are probably applicable for other host species or locations, but additional survey is needed to refine estimates for particular areas if precise figures are desired. Also, even if conks are absent, the extent of decay, if any, can still be estimated. Two logistic equations were developed to estimate the percentage of infection by the Indian paint fungus and stem decay by all fungi in advance grand or white fir regeneration in eastern Oregon and Washington. The decay equation was subsequently validated for grand fir in northern Idaho. The equations have not been validated in other areas or with other host species.

The first equation estimates the percentage of potential leave (crop) trees with both dormant and active trunk infections of the Indian paint fungus (ET%):

Decay (cull) rules for rust-red stringy rot in white fir and Shasta red fir in Southwest Oregon.

Conk age, number, and location:	Decay extent:
Conk is single, small, and young	8 ft. above and below conk
Lowest conk is 0 to 32 ft. from ground Multiple conks are separated by <25 ft.	12 ft. below lowest conk; 21 ft. above highest conk
Lowest conk is >32 ft. from ground Multiple conks are separated by <25 ft.	20 ft. below lowest conk; 21 ft. above highest conk
Conks are in bottom third of tree	Decay in the middle and bottom third of tree
Conks are in top third of tree	Decay in top and middle third of tree
Multiple conks are separated by >25 ft	Decay in the entire tree

LOG_N (ET%) = 1.1832 (OVER) – 0.0632 (LCR) + 6.3909

Where: OVER = Primary overstory species (0 = pine, 1 = fir)

LCR = Mean leave-tree live-crown ratio (percent)

LOG_N = Natural logarithm

(R^2 = 0.42, SE = 0.98)

The second equation estimates the percentage of stand leave-tree volume (ft^3) (DEC VOL%) with both incipient and advanced decay caused by all fungi including *E. tinctorium*:

LOG_N (DEC VOL%) = 1.8219 LOG_N (AGE) + 0.8386 LOG_N (WND%) – 0.4151 (ASP) – 10.4222

Where: AGE = Mean leave-tree total age

WND% = Percentage of leave trees with one or more wounds ($\geq$1 in^2) or conks

ASP = Stand aspect (0 = N, NW, NE, W; 1 = S, SE, SW, E)

(R^2 = 0.70, SE = 0.79)

True-fir stands can be sampled by following one or more parallel transects through the stand and selecting one potential leave tree (based on height, form, live-crown ratio, and wounding) nearest a sample point located every 100 ft. along the transect. The idea is to systematically obtain at least 20 sample trees per stand. Below are examples of five true-fir stands with collected and current estimated values as well as projected values at 100 years using the two equations above.

Stand	Current stand age (yrs)	Mean live crown ratio (%)	Trees with wounds or conks (%)	Overstory species[1]	Aspect[2]	Estimated trees with Indian paint fungus (%)	Current estimated ft^3 decay volume (%)	Age 100 wound (%)[3]	Age 100 dec. vol. (%)
1	109	63	40	1	0	36	3.4	39	2.8
2	61	83	50	1	0	10	1.4	54	3.7
3	68	85	15	0	0	3	0.6	18	1.5
4	74	70	20	1	1	23	0.6	23	1.2
5	104	61	80	0	1	13	3.7	80	3.4

[1]Overstory species: 0 = pine ($\geq$60% vol. or BA), 1 = fir (>40% vol. or BA)

[2]Aspect: 0 = N, NE, NW, W; 1 = S, SW, SE, E

[3]Number of wounds increases naturally at 1% per decade

Management

Decisions on how to manage true fir or hemlock stands depend on objectives, the levels of Indian paint fungus infection and decay, and the occurrence of and vulnerability to other pathogens and insects. Regarding Indian paint fungus, fir stands with a relatively low incidence (<25%) of wounding and good live-crown ratios (>50% under pine and >75% under fir) generally have low infection levels (<20%) and low decay percentages (<2% at 100 years), such as stand #3 in the table above. For timber or recreation objectives, such stands can be managed for 150 years with no special precautions, provided that substantial tree injury does not occur and reasonable growth increment is maintained.

Stands with a high incidence of wounding but good live-crown ratios usually have low infection levels but high decay percentages, such as stand #5 above. Unless decay is desirable for wildlife or other purposes, such stands should be managed for less than 150 years. These stands should be thinned early to maintain good live-crown ratios and remove wounded trees. Additional wounding should be prevented.

Stands with a low incidence of wounding but poor live crown ratios usually have high infection levels but low decay percentages, such as stand #4 above. Trees in these stands should be thinned to improve live-crown ratios and leader growth. Tree wounding should be prevented using established guidelines (see below). These stands probably can be managed for 80 to 100 years.

Stands with a high incidence of wounding and poor live-crown ratios usually have high infection levels and high decay percentages, such as stand #1. Such stands can be maintained for wildlife purposes, if that is an objective, but will probably begin to deteriorate when they reach 80 years of age. These stands should be replaced or the fir component salvaged if timber production or public safety from hazard trees is important.

From a hazard-tree context in developed recreation sites, trees with one or more conks have an elevated failure potential and should be evaluated based on conk and wound size, number, and location; other site and stand factors; and proximity to potential human and structural targets. Treatment may be needed if trees have a combination of excessive failure and damage potential. From a danger-tree context along roadsides or in the workplace, trees with multiple conks, wounds, or other decay indicators have likely failure potential. Such trees should be treated within 1 to 3 years of evaluation, depending on frequency and duration of road traffic or work activity.

There are several ways to prevent tree wounding and subsequent decay from the Indian paint fungus and other decay fungi:

1. Properly use different types of operating equipment for appropriate site and stand conditions.

2. Monitor the thinning or harvesting operation and gain the cooperation and understanding of the equipment operator.

3. Avoid spring or early summer activities near host trees.

4. Mark “leave” trees rather than “cut” trees when thinning or harvesting.

5. Plainly mark skid trails and skyline corridors before tree marking and logging.

6. Make trails and corridors straight and wide.

7. Space trails to keep equipment on them.

8. Cut stumps low in skid trails or use old skid trails where high stumps are not common.

9. Protect trees near skid trails or corridors with plastic covers or similar protective devices around trees, especially near trail corners.

10. Use rub (bump) trees or high stumps near corners in skid trails or corridors.

11. Use directional felling, and fell to openings at 45º.

12. Place chokers near the ends of logs when winching or lateral yarding.

13. Remove slash and debris from within 10 feet of leave trees to reduce damage from fire.

14. Favor decay-resistant, resinous species such as ponderosa pine or Douglas-fir when planning or thinning in developed-recreation sites.

In situations where it is desirable to do so, decay caused by most species of fungi in live true fir and hemlock trees can be promoted or increased for wildlife habitat by wounding appropriate trees. The following approach is recommended although any kind of wounding has a high likelihood of favoring decay in those tree species:

1. Drill two or three holes 1 inch in diameter and 6 inches deep into the trunk. Use a hand drill or battery-powered drill.

2. Halfway into each hole, place a 6-inch piece of plastic pipe to allow air exchange for several years and easier monitoring of treated trunks.

3. Place holes at least 25 feet above ground for cavity-nesting birds to reduce attack by ground-dwelling predators.

4. Drilling may or may not activate Indian paint fungus infections in true fir or hemlock, but even if it does not, it may facilitate airborne infection and subsequent decay by other fungi.

5. Although dead and decayed trees will accommodate wildlife in some situations, living decayed trees are often preferable because they will remain standing and maintain viable habitat longer than dead trees. Also, only living trees can form hollows (compartmentalized decay), so that hollow logs on the ground only result from trees that became hollow while alive. Hollow logs serve as critical habitat for a certain suite of wildlife species.

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