

Effect of *Armillaria* Root Disease on Stand Structure, Composition, and Potential Fire Behavior in a  
Managed Ponderosa Pine Forest near Glenwood, WA

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### Abstract

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Root disease and wildfire are important disturbance agents in western North American forests. It has been speculated that root disease increases potential fire behavior, since root disease kills trees and contributes to available fuels. However, little quantitative evidence of this effect on wildfire has been offered. This research quantifies the effect of *Armillaria* root disease on potential wildfire behavior in a managed ponderosa pine (*Pinus ponderosa*) forest near Glenwood, Washington. *Armillaria*, like other conifer root diseases, creates slowly expanding centers of tree mortality. Forest structure and composition data were collected from paired plots within and outside of mortality centers. Differences in forest structure and composition variables were identified using pairwise t-tests with  $\alpha = 0.05$ . Plant community composition was largely the same between plot types, with slightly more grasses in the diseased plots. There were several differences in stand structure: diseased plots had lower basal area and density in the overstory and midstory canopy, diseased sites had more snags in the older age classes, and diseased plots had higher 100 and 1000 hr fuels. Two fuelbeds were created based on these differences and fire behavior was modeled using the Fuel Characteristic Classification System (FCCS).

FCCS calculates standard fire behavior metrics as well as fire behavior potentials calculated on a unit-less 0-9 scale which reflects the ability of a fuelbed to support a given fire behavior. Overstory canopy cover was significantly reduced in plots with *Armillaria*. There was no difference in abundance of ladder fuels. This led to a decrease in crown fire potential in the diseased fuelbed. Significantly greater 100 and 1000 hr fuel loadings were detected in the diseased plots but no differences in 1 and 10 hr fuels. There were also differences in forest floor litter. Few differences were detected in the shrub or herb layers. Increased reaction potential for surface fire was predicted for the diseased fuelbed, however rate of spread (ROS) and flame length were reduced. The simultaneous increase in reaction potential and decrease in ROS and flame length in the diseased fuelbed is counterintuitive. Increased 100 and 1000 hr fuels in the diseased fuelbed initially act as a heat sink, absorbing the energy of the flaming front. This study suggests that root disease may decrease wildland fire severity and highlights the need to consider multiple competing effects when assessing the impact of disturbances on wildland fire.

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## **DEDICATION**

To the mountains, forests, and streams; and to the people who've got me here.

## Introduction

Concern over the health of the dry forests of the western US has grown in recent years as fires have increased in size and intensity, insect outbreaks have destroyed countless acres, and diseases continue to take their toll. There is an intuitive connection between forest mortality agents, such as insects and disease, and increasing fire behavior. As trees are killed they dry, fall to forest floor and increase fuels, thereby intensifying fire behavior. However scientific investigation into this hypothesized effect has produced inconsistent and contradictory results. Even the effect of mountain pine beetle (*Dendroctonus ponderosae*), on fire behavior is contentious, and this is by far the most researched mortality agent-fire interaction (e.g., Simard et al. 2011). Outside of the scientific community most believe that mountain pine beetle and other mortality agents increase potential fire behavior.

Root diseases are also implicated in increasing fire hazard in the forests of western North America. Root diseases typically kill slowly, and remain on a site indefinitely causing slow and subtle changes to forest structure and composition in comparison to bark beetle outbreaks. Therefore expected changes in fire behavior are expected to be more subtle. Understandably the effect of root diseases on wildfire has received relatively little attention. Several studies have linked root disease to elevated woody fuel levels. Lundquist (2007) provided evidence from the Black Hills of South Dakota that root disease increases surface fuel loads. Fields (2003) found increased fuel loadings associated with root disease in central Oregon, and Hessburg et al. (1994) hypothesized a similar effect in eastern Washington forests.

While insect and disease mortality undoubtedly increases surface fuel loads, Knight (1987) pointed out that they may affect fire behavior in many other ways for example plant communities may change, as was demonstrated by Holah et al. for root disease (1993, 1997); microclimate may be affected; forest floor litter may change; etc. All of these factors can impact fire behavior in a stand. To

my knowledge there is no study which attempts to quantify differences in all these variables, or one which looks directly at the effect of root disease on actual or predicted fire behavior.

Determining the relative influence of any mortality agent's effect on fire behavior is challenging. A disease may increase fire behavior in one way, while simultaneously decreasing it in another. For example *Armillaria* root disease may increase the density of snags susceptible to torching in a stand while also decreasing tree density and reducing the potential for crown fire to spread. The creation of the Fuel Characteristic Classification System (FCCS) provides a holistic approach to quantifying potential fire behavior (Ottmar et al. 2007). It allows for customization of fuelbeds at various canopy layers based on forest structure and composition variables measured in the field. This modeling approach, within the context of Knight's (1987) conceptual model, was used to test the assumption that root pathogens can increase flammability in dry forests of the western US.

The objectives of this study were (1) to determine how *Armillaria* root disease influences stand structure, plant species composition, and fuels in a managed ponderosa pine (*Pinus ponderosa*) forests near Glenwood, Washington and (2) to quantify the effect of root disease on potential surface and crown fire behavior in this same area. This will allow a quantitative discussion about the effect of root disease on fire behavior. Secondly it demonstrates the applicability of the FCCS fire behavior model for investigating the effect of insects and pathogens on potential fire behavior.

## Literature Review

### *Ponderosa Pine Ecology*

Ponderosa pine grows throughout western North America from northern Mexico to southern British Columbia (Critchfield and Little 1966). In Washington it grows predominantly east of the crest of the Cascade Mountains from about 600 to 1200 m in elevation (Franklin and Dyrness 1988). The Ponderosa Pine Zone (sensu Franklin and Dyrness 1988) occupies the lowest elevation, driest forested sites in Washington State. At upper elevations it transitions into the Douglas-fir and Grand fir Zones (Van Pelt 2008). At the lowest elevations the Ponderosa Pine Zone transitions into arid steppe vegetation. While these generalizations suffice to describe the distribution of ponderosa pine at the regional scale, other factors influence the occurrence at smaller scales. For example, at Glenwood, Washington land use and soils play a major role in determining the extent of ponderosa pine (pers. obs.)

Ponderosa pine is shade intolerant, and a common seral component in the Douglas-fir Zone, where it is unlikely to successfully reproduce without disturbance, such as fire. Seed germinates best in mineral soil. Roots penetrate deeply into the soil to maximize their ability to uptake water and thus ponderosa pine commonly occupies droughty sites.

The importance of fire in maintaining ponderosa pine forests has been understood by ecologists for decades (Agee 1993). Frequent low intensity fire favors fire resistant large diameter ponderosa pines and maintain an open, low density stand structure (van Pelt 2008). Changes in ponderosa pine forest structure and composition since the settling of eastern Washington have been documented including: selective logging of large diameter pines, grazing by ungulates, and perhaps most importantly fire suppression; current ponderosa pine forests are characterized as denser forests of smaller diameter trees than pre-fire suppression stands (Camp 1999, Harrod et al. 1999, , Hessburg et al. 2005).

Ponderosa pine is a host to a variety of insects and pathogens. Mountain pine beetle (*Dendroctonus ponderosae*) is a common primary killer of groups of mature trees as well as overstocked young stands (Goheen and Willhite 2006). Under endemic population levels the beetle preferentially selects stressed trees in overstocked stands, but in an epidemic there is no selection preference. Historically billions of board feet of ponderosa pine as well as lodgepole pine (*Pinus contorta*) and other tree species have been killed by mountain pine beetle (Furniss and Carolin 1992). Western pine beetle (*Dendroctonus brevicomis*) is commonly found in weakened ponderosa pine, including those with root rot. Under epidemic conditions it can become an aggressive tree-killer. Overall, however, the western pine beetle is much less destructive than the mountain pine beetle (Goheen and Willhite 2006).

*Heterobasidion irregulare* and *H. occidentale* (formerly *H. annosum*) that cause Annosus Root and Butt Rot and *Armillaria ostoyae* (synonym *A. solidipes*) that causes Armillaria root disease, are important pathogens of ponderosa pine (Goheen and Willhite 2006). These pathogens can spread from tree to tree via root contact, and can persist in stumps, root fragments, and soil for decades. Both root diseases can produce expanding canopy gaps as a result of tree mortality.

Western dwarf mistletoe (*Arceuthobium campylopodum*) is a non-photosynthetic angiosperm which is parasitic on branches of ponderosa pine (Goheen and Willhite 2006). It is a common disease and causes the formation of atypical clusters of branches known as “witches’ brooms.” These brooms serve as important habitat components for several wildlife species. Mistletoe steals nutrients and water from the host tree reducing growth and vigor of the tree which can contribute to eventual mortality (Edmonds et al. 2011). It may also contribute to ladder fuels in stands where fire has been suppressed.

Many other biotic, and abiotic, disturbance agents affect the forests around Glenwood, Washington. Notably a massive pine butterfly (*Neophasia menapia*) outbreak on the Yakama Indian Reservation in 1893 resulted in extensive mortality of ponderosa pine and subsequently a large area of

even-aged forest (Weaver 1961). All of these diseases and insects operate together on the landscape and doubtlessly have complex interactions (Parker et al. 2006).

### *Armillaria Ecology and Pathology*

*Armillaria* is a basidiomycete genus which occurs worldwide from tropical to boreal regions (Shaw and Kile 1991) and its ecology in the world's forests is discussed in Kile et al. (1991). It causes root and butt rot of woody plants in natural forests, plantations, and landscaping and agricultural settings. *Armillaria* species exist on a spectrum from aggressively pathogenic to mostly saprophytic (Edmonds et al. 2011). In western Washington *Armillaria* is often associated with trees of poor vigor in overstocked stands. However, in eastern Washington *Armillaria* can be a destructive pathogen attacking dominant overstory trees. Like many fungi, the taxonomy and nomenclature of *Armillaria* has been debated. Prior to the 1980s most *Armillaria* isolated in North America was identified as *Armillaria mellea*. Since that time DNA analysis has been used to separate different species (Sinclair and Lyon 2005) and nine species have been identified in North America. The most pathogenic of these is *Armillaria ostoyae*. This is the fungus at Glenwood (Roth et al. 2000) and this name is used in my study. However, there has recently been a suggestion that it should be renamed *Armillaria solidipes* (Bursdall and Hunt 2008).

Symptoms of *Armillaria* root disease are common to other conifer root diseases and include chlorotic foliage, reduced leader growth, stress crops of small cones which are typically small, and resinous "weeping" at the base of the tree. However, signs are distinctive and include distinctive cream-colored mycelial fans beneath the bark of roots and stems, flattened black rhizomorphs in the soil and beneath bark, and ephemeral masses of honey-colored basidiocarps in autumn.

Commonly the fungus spreads from a central infected tree or stump forming infection centers. Shaw (1974) describes, "Infection centers... marked by several recognizable, more or less concentric zones. An old-growth stump or stumps and a clump of healthy-appearing saplings frequently are found

near the middle of the infection center. Outward from the stump and saplings is an area that is unstocked or poorly stocked, but free of significant coarse woody debris. This zone is surrounded by a broad band where the ground is littered by coarse woody debris. Outward from this band is a zone of stumps and standing 'snags' of increasing height toward the outer limits." This pattern is still recognizable on the ground today, though there is much variation. The infection center as described above is often the first symptom of *Armillaria* that land managers notice.

*Armillaria* spreads by airborne spores and rhizomorphs, specialized structures composed of many strands of mycelia with a protective outer coating that grows through the soil, which can cause infection when they contact uninfected roots. The disease is also spread when roots of an uninfected tree come into contact with infected material. The infection may be confined to one location or may spread distally causing mortality. This effect can be innocuous on a healthy tree if the initial infection occurs in an outer portion of a root. However, the infection is often lethal if it occurs high on the taproot or at the root collar (Reaves et al. 1993). Since the disease readily spreads through the soil, pockets of mortality are commonly expressed on the landscape where aggressively pathogenic strains are prevalent. This is especially true in the area of this study, near Glenwood, Washington. The fungus can spread as quickly as 1 to 2 m/yr and is thought to persist in the dead woody material on a site for 35 years or more (Hadfield et al. 1986).

Some sites are more susceptible to *Armillaria* than others. McDonald (1990) examined relationships among site quality and stand structure and *Armillaria* root rot in Douglas-fir forests and found that very warm and dry habitat types – e.g., the *Pseudotsuga menziesii*/*Festuca scabrella* (PSME/FESC) association and *Pinus ponderosa* (PIPO) series have low occurrence of *Armillaria*. The occurrence increases along a moisture gradient to a maximum in the ABGR/PHMA (*Abies grandis*/*Physocarpus malvaceus*) association. However, the *Armillaria* at Glenwood occurs primarily in dry low-elevation sites and is particularly aggressive.

Although clearly negative from a timber production point of view the potential positive ecological effects of *Armillaria* are now being explored. However, there has been little work on the influence of *Armillaria* on stand structure and species composition in the Pacific Northwest. Some research has been conducted with Laminated root rot caused by *Phellinus sulphurascens* (formerly=*P. weirii* (Murr.)Gilbertson). Hansen and Goheen (2000) reviewed the effects of Laminated root rot and Holah et al. (1997) showed site-specific understory vegetation changes with *P. weirii* in western Oregon. Steeger and Hitchcock (1998) documented that red breasted nuthatches (*Sitta canadensis*) prefer dead trees infected with *Armillaria* for nesting. This is attributed to the relative ease that the birds have of excavating nesting cavities. It appears, however, that the presence of dead trees, and not just *Armillaria* infected trees, was the important factor. *Armillaria* increases the amount of dead trees.

Research on *Armillaria* at the Glenwood location dates back at least to the 1950 (Shaw 1974). Shaw determined that *Armillaria mellea* was the primary pathogen at the site. He found that lateral roots are commonly killed distally to infection, but that such infections have little impact on the tree. In contrast infections high on the tap root typically kill the tree. Shaw (1974) speculated that it was human management of the forest that resulted in the “extreme level of forest destruction.” He hypothesized that dead stumps and root material provided an abundant food source which led to a buildup of inoculum. Working in an area of the Glenwood forest just west of my study area Shaw and Roth (1976) calculated an average spread rate of 1 m/yr. Using this figure they calculated the *Armillaria* colony would be at least 460 years old. In another study Ferguson et al. (2003) determined a 2400 acre (1091 ha) *Armillaria* clone to be more than 2000 years old terming it the “humungous fungus.”

## *Fire Behavior and Ecology*

Fire is an important disturbance agent in the dry forests of Western North America (Agee 1993). From stand replacing crown fires, to low intensity ground fires- fire plays an important role in shaping forest landscapes. Fire ignitions can be natural (e.g., lightning), or human caused (e.g., prescribed fire). In either case fire typically starts by consuming and spreading through dried woody debris and litter on the ground. This is known as a surface fire. The behavior of a surface fire is driven primarily by: (1) the distribution, density, and moisture content of fuel; (2) wind speed; (3) ground slope; and (4) air temperature. Surface fuels consist of duff (the layer between mineral soil and surface litter), surface litter, herbaceous and shrub vegetation, and dead woody fuels which are separated into diameter classes. Diameter classes are determined by the time necessary for the fuel to reach a new equilibrium moisture content given a change in the relative humidity of the air. Typically these classes are defined as 1, 10, 100, and 1000 hr fuels. Larger diameter fuels take longer to dry (or absorb water) than smaller diameter fuels. The rate of spread (ROS) of the fire, and the flame length are fire behavior metrics that are important to consider in tactical fire management. The amount of energy released by the fire, or fire intensity, is another critical fire behavior metric (Agee 1993).

As a fire proceeds through a forest stand the energy released can dry vegetation above and in front of the flaming front by convective processes. If the vegetation above the flaming front reaches critically low moisture content from this drying, and flame lengths are sufficiently high, canopy fuels can begin to ignite. Continuity of fuel from the forest floor to the canopy, known as ladder fuels, can also help the transition from ground to canopy fires. The transition from surface fire to canopy fire is driven primarily by surface fire reaction intensity, flame length, height of ground fuels and canopy fuels, and the presence of ladder fuels (Agee 1993).

Individual trees or groups of trees can ignite, known as single-tree or group torching, respectively. However, if the forest is sufficiently dense and wind speeds high enough, the flaming front may be carried from canopy to canopy in an active crown fire or canopy fire. Stand density, fuel moisture, and wind speed are important drivers of crown fire behavior (Agee 1993).

The effect of fire on a forest, or the fire severity, depends on the intensity of the fire and the ability of the vegetation to resist fire damage. Fire regimes primarily describe the intensity and frequency of fires in a region. Plants with adaptations to resist fire damage are typically found in areas with frequent low intensity ground fires. This is known as a low severity fire regime. Plants with little resistance to fire injury, but sometimes with the ability to easily recolonize following a fire, are often found in areas with infrequent, high intensity fires. This is known as a high severity fire regime. Where there is a mix of tree species with varying degrees of fire-resistance, a third fire regime or mixed-severity fire regime is common. A mixed-severity fire typically has areas of low and high severity, and gradients between the two. Very different landscape patterns develop under the different fire regimes (Agee 1993).

#### *Disease Effects on Potential Fire Behavior*

Root disease affects forest composition and structure, which in turn may affect potential fire behavior. It may reduce overstory cover, change species composition in various canopy layers, and increase surface fuel loadings. Knight (1987) provided a conceptual framework wherein diseases affect forest flammability through the fuel complex, stand structure, and species composition. Although Knight (1987) described the disease/fire interaction as being complex, studies of the effect of root disease on forest flammability have focused largely on fuel loading. The connection is intuitive - root diseases kill trees, which eventually fall to the forest floor increasing fuel loading. However, there are few quantitative studies of the effect of root disease on fuel loading (but see Fields 2003 and Lundquist

2007). Furthermore, fuel loading is only one of the many potential ways that root disease may impact fire behavior.

Several studies have examined the effect of insects, particularly the mountain pine beetle, on potential fire behavior (Jenkins et al. 2008, Kultsch et al. 2011, Simard et al. 2011), but there are few quantitative studies of the effect of forest pathogens on potential fire behavior. Lundquist (2006), working in ponderosa pine forests of the Black Hills of South Dakota, studied the relative importance of nine small-scale disturbances in contributing to fuel loading. Lundquist's "FUEL LOAD" response variable was calculated by combining measures of various diameter classes of woody fuels as well as litter and duff measurements. Of the disturbances studied, only root rot, primarily caused by *Armillaria ostoyae*, was a significant predictor of fuel loading in all models. Root rot also had the largest direct effect on fuel loading. Lundquist concluded that, "...the most important fuel generating disturbance in the area studied is root rot." In another study, Fields (2003) studied the effect of root disease, caused by both *Armillaria spp.* and *Heterobasidion annosum*, on stand structure in true-fir (*Abies spp.*) forests in central Oregon. She found a significant positive relationship between the basal area of trees infected with root disease and an aggregated measure of dead woody fuel loading. Interestingly, when the aggregated variable was broken into its constituent diameter classes only 100 and 1000 hr fuels had a significant relationship with infected basal area. Smaller diameter fuels were not affected.

Several studies have examined the role of root pathogens in determining forest structure and composition. Although these studies were not focused on fire behavior, they indicate how disease may affect fire behavior beyond just increasing fuel loads. Holah et al. (1997) surveyed plots within *Phellinus sulphurascens* mortality gaps and compared them with plots in adjacent unaffected forest in five locations across western Oregon. They found differences in the composition of both overstory and shrub communities. Predictably the susceptible tree species, Douglas-fir and mountain hemlock (*Tsuga mertensiana*) in this study, were less abundant in mortality gaps. Elevation or geography had an

important interaction with *P. sulphurascens* in determining the changes in species composition. In an earlier study Holah et al. (1993) concluded that *P. sulphurascens* “can significantly impact community composition.” They did not consider fire because they worked in wetter climates. Root disease, however, may have similar effects in drier forests where the impact on fire behavior may be important. It should be noted that diseases, insects and fire strongly interact in interior western coniferous forests (Parker et al. 2006).

#### *Effect of Other Disturbances on Potential Fire Behavior*

The effect of bark beetles (*Dendroctonus spp.*) on potential fire behavior is perhaps the most researched. However, results are not conclusive. Jenkins et al. (2008) reviewed dozens of papers over more than twenty years of research and concluded that bark beetle-fire interactions are “poorly understood.” Bark beetles often cause widespread tree mortality in short periods of time. This leads to changes in fuels, stand densities, and species composition which occur relatively synchronistically over years to decades. Bark beetles have caused changes in the drivers of fire behavior which are relatively homogenous over 10s to 1000s of acres for decades.

Simard et al. (2011) used NEXUS (an Excel spreadsheet linking surface and crown fire prediction models – <http://fire.org>) to model crown fire behavior in a chronosequence of mountain pine beetle infestations in lodgepole pine stands in Wyoming. They concluded that probability of active crown fire decreases initially post-epidemic because canopy bulk-density, a primary driver of crown-fire models, is reduced as trees die. They also could not detect short-term increases in fine-surface fuels following an epidemic. Klutsch et al. (2009) similarly did not detect differences in fine surface fuels, although several studies have (Page and Jenkins 2007; Jenkins et al. 2008). It will likely be even harder to achieve consensus on the effects of root diseases which take decades to spread several feet leaving a heterogeneous mortality gap .

There are few studies of the effects of other biotic disturbances on wildfire behavior. Hoffman et al. (2007) attempted to quantify the effect of southwestern dwarf mistletoe (*Arceuthobium vaginatum*) on potential fire behavior. They observed lower live tree density and higher snag density in sites with severe infestations of dwarf mistletoe. They also observed higher total surface fuel loadings, driven by significant differences in 100 and 1000 hr fuels. Hoffman et al. (2007) observed that lower wind speed was required to transition surface fire to the canopy in severely infested stands. However, they failed to detect any differences in canopy fuel loading because they used allometric equations to estimate canopy fuels. These equations do not account for changes in the canopy due to mistletoe induced witch's brooms.

A recent study of the effect of Sudden Oak Death (caused by *Phytophthora ramorum*, an actively invading non-native pathogen), on wildfire severity in California highlights the importance of temporal changes that occur as the disease spreads through a forest (Metz et al. 2011). They could not detect a difference in fire severity between infected and uninfected stands. However, they concluded that overstory burn severity was significantly worse in areas where *P. ramorum* had recently invaded.

Hummel and Agee (2003) investigated the effect of western spruce budworm (*Choristoneura occidentalis*) defoliation (of *Abies* and Douglas-fir) on forest structure and potential fire behavior in a mixed conifer forest in south-central Washington. They concluded that surface flame lengths were increased by additions of large diameter fuels. However, torching potential and crown fire intensity were reduced as canopy cover and tree density were reduced.

The effect of biotic disturbance on wildfire behavior, potential or actual, is complex. There are many interacting and confounding effects. Fire behavior often responds differently to a disturbance (e.g., surface fire and canopy fire). Biotic disturbance agents themselves often interact adding to the

complexity. It is important to examine all the pathways by which disease can affect fire when drawing conclusions on the effect of disease.

#### *Effect of Fire on Root Disease*

In addition to disturbance effects on fire behavior, fire may also directly affect forest diseases. However, there is little research or agreement on the effect of fire on root diseases. Littke and Gara (1986) provided evidence that fire can increase the prevalence of decay fungi. Working in lodgepole pine in south central Oregon, they reported that trees damaged by fire were significantly more likely to develop heart-rot. In all cases fire-damaged roots were also decayed.

Fire is not thought to have a great impact on the prevalence of *Armillaria* root disease. Filip and Yang-Erve (1997) showed that prescribed fire reduced the recovery of *A. ostoyae* from stem segments buried at 8 cm, but had no effect at 30 cm. Also, clones of *Armillaria* have been able to thrive and grow for hundreds of years in fire prone ponderosa pine stands (Shaw and Roth 1976, Ferguson et al. 2003). Given this information it seems unlikely that fire plays a major role in controlling *Armillaria*. However, wildfire in an overstocked stand is likely to be much more intense than the prescribed fire studied by Filip and Yang-Erve (1997).

There is evidence that *Heterobasidion annosum* occurrence may be reduced by fire. Lygis et al. (2010) surveyed mortality centers caused by *Heterobasidion annosum* in Lithuania, which were burned in a wildfire as well as mortality centers outside the fire perimeter. They recovered significantly less *H. annosum* from root systems in the burned sites 1 and 2 years after the fire. An earlier study showed the prescribed burning can reduce the severity of *H. annosum* infection in pine plantations in the southeastern US (Froelich et al. 1978). The specifics of the site and the disturbance intensity are important in determining the ecological effect.

### *Gap Microclimate*

Temperature, fuel moisture content, windspeed, and relative humidity are important drivers of fire behavior that can vary on small scales with soil and air temperatures higher in lower density patches of forest (Heithecker and Halpern 2006). Increased windspeed and air temperature were found in thinned stands in southeastern British Columbia, although there was no difference in relative humidity (Whitehead et al. 2006). Fine fuel moisture was generally lower in thinned stands, however, as sites dried values converged. At the highest fire danger levels fine fuel moisture was equivalent between thinned and unthinned sites (Whitehead et al. 2006).

*Armillaria* root disease likely affects microclimate similarly at the Glenwood, Washington site driving changes in potential fire behavior. However, microclimate was not investigated in this study for lack of resources. Albini and Baughman (1979) constructed a model to account for stand density in calculating windspeed beneath the forest canopy. This model has been widely used in research on the interactions of pest and pathogen and fire (e.g., Page and Jenkins 2007, Simard et al. 2011). However, the Albini-Baughman model is inappropriate for application in this study of root disease because *Armillaria* causes canopy gaps which are highly irregular in shape and produces vertical structure violating the model assumption of “uniform continuous vegetation cover” (Albini and Baughman 1979). Therefore this study does not attempt to quantify microclimate effects of *Armillaria*.

### *Fire Behavior Modeling*

Fire behavior modeling provides a powerful tool for assessing the effect of forest disturbances on wildfire behavior. Modeling can account for the fact that a single disturbance may affect many of the drivers of fire behavior. This is especially important where a disturbance affects variables in ways that have contradictory effects on fire behavior, e.g., by increasing woody surface fuels, but decreasing needle-litter. Fire modeling was originally developed as a tool for fire managers to assist with fire

suppression and pre-fire management. However, it is also useful in assessing potential fire behavior in more ecological applications. Surface fire is better understood than crown fire behavior and therefore surface fire modeling is more widely accepted (Cruz and Alexander 2010). Many studies use fire behavior models to evaluate the effect of various forest disturbances on wildfire potential (Hummel and Agee 2003, Hoffman et al. 2007, Page and Jenkins, 2007, Jenkins et al. 2008, Simard et al. 2011).

Several studies of disease and fire interaction have looked only at the effect of disease on dead fuel loadings (Fields 2003, Lundquist 2007). Many other variables affect potential fire behavior, and it is insufficient to draw conclusions from looking at only one variable. Any given forest stand likely has characteristics that serve to increase and diminish the intensity of potential fire behavior. For instance a stand could have heavy loads of needle litter, which could increase the rate of surface spread, while simultaneously having low grass cover. An adjacent stand may have low needle litter but high grass cover. The only effective way to compare these two stands is with a model that accounts for the differences in flammability of grass and needle litter. However, this expands the example from just two variables to a whole suite of vegetation species, down woody debris, etc. The Fuel Characteristics Classification System (FCCS) is a tool designed to assess the impact of many variables on potential fire behavior. The developers of FCCS even saw its usefulness for addressing the question of the effect of pathogens on fire behavior (Ottmar et al. 2007).

FCCS goes beyond Albini's (1976) 13 fuel models and Scott and Burgan's (2005) 56 fuel models to allow managers and researchers to customize fuelbeds for their own work and to share with others. Once the fuelbeds are characterized, fire behavior predictions are calculated similarly to previous fire models. Prediction of fire spread by FCCS and previous models like Behave and Nexus are all based on Rothermel's fire behavior (1972) equations. The main difference with FCCS is that it allows fuels to be represented more realistically. A key limitation to Rothermel's equations is the assumption of a

homogenous fuelbed. FCCS attempts to circumvent this limitation by creating a more precise comparison of surface fire behavior between two fuelbeds.

### *Root Disease Modeling*

Land managers are also keen to predict the expansion and effect of root diseases in a forest stand. The Western Root Disease Model was developed by US Forest Service researchers in the 1990s as a sub-model to the Forest Vegetation Simulator (FVS). It models the expansion of a root disease center, the amount of an individual tree's root system that is infected, tree mortality, tree decay, and inoculum level of the site. *Armillaria ostoyae*, *Phellinus weirii*, *Heterobasidion annosum* S-Type, and *H. annosum* P-type have unique parameters in the model (Frankel 1998). The Western Root Disease Model was not used in this study primarily because its data requirements were not compatible with the data being collected for FCCS fire behavior modeling, which was used in this study.

## Methods

### *Study Location, Climate, Soils and Vegetation*

This study was conducted in Washington Department of Natural Resources (WA-DNR) parcels near the town of Glenwood in western Klickitat County in south-central Washington (N 46°02', W 121°17') (Figure 1). All sites were located between 1800 and 2000 ft (549-610 m) in elevation just east of the Cascade Crest at Mt. Adams.

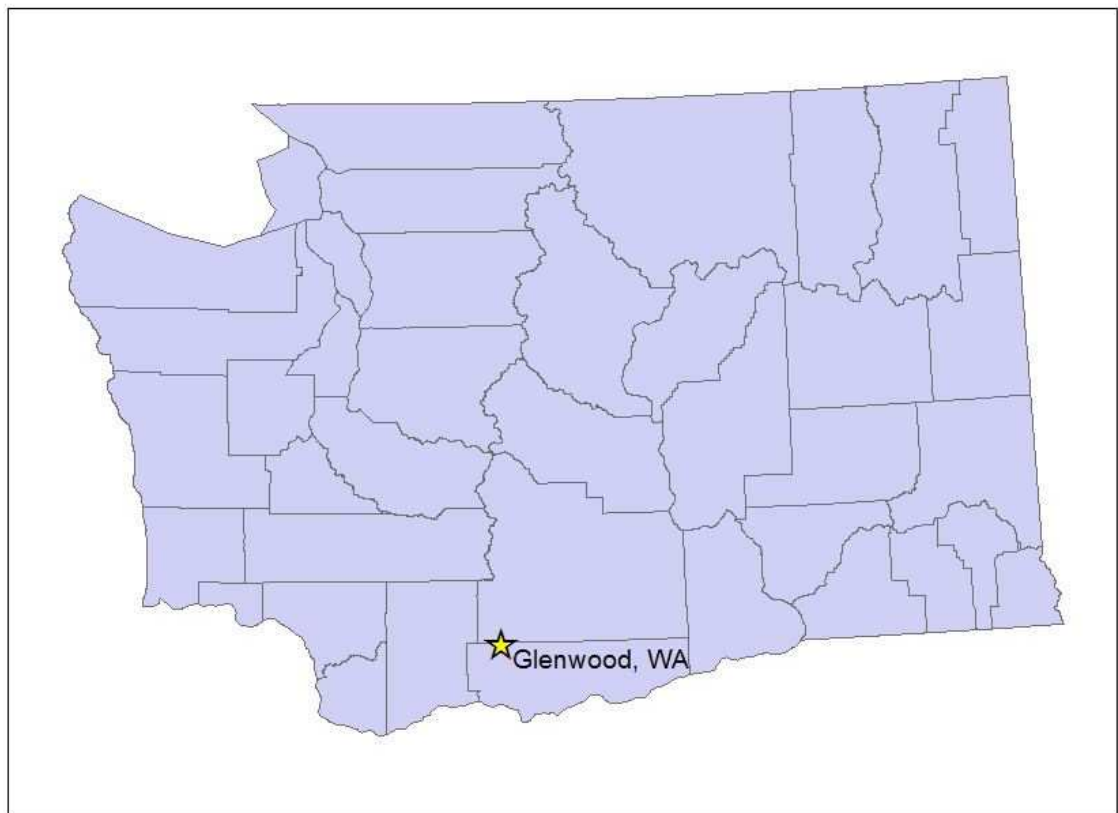


Figure 1. Location of study area near Glenwood, Washington.

The climate at Glenwood is Mediterranean, but is influenced by the interior Columbia River Basin. For the period 1979-2005, the average maximum monthly temperature in August was 81°F (27.2 °C), while the average minimum monthly temperature in December was 23°F (-2.8°C) (Western Regional Climate Center 2012). Annual precipitation averaged 31 in. (78.7 cm) with 24 in. (63.5 cm) falling

between November and March and only 0.5 in. (1.3 cm) in July and August combined. Much of the winter precipitation falls as snow, 58 in. (147.3 cm) annually.

Soils are Andisols, Alfisols and Mollisols. Sample plots were distributed through five soil series: Icksix (Typic Vitrixerands), Guler (Humic Vitrixerands), Pinbit (Humic Vitrixerands), Carmack-Rock Outcrop-Complex (Ultic Argixerolls), and Trelok Variant (Andic Haploxeralfs). All plot pairs were located within one soil series with the exception of the pair of sample points 33 on a Trelok Variant, and 35 on a Carmack-Rock Outcrop Complex (Natural Resource Conservation Service 2009). The Icksix and Guler series are stony, sandy loams. Icksix is derived from volcanic ash over igneous bedrock. Guler is derived from volcanic ash over alluvium as is Pinbit, a stony loam. The Carmack-Rock Outcrop-Complex is a mix of bedrock outcroppings and Carmack soil. The Carmack soil is a cobbly loam derived from volcanic ash over non-calcareous sedimentary bedrock. The Trelok Variant is a silt-loam derived from volcanic ash over basic igneous bedrock. It is the finest textured soil in the study area. As such it is moderately well drained, while the others are well drained. Overall the soils are droughty and display the evidence of nearby volcanism. Volcanic ash is common in all the soil profiles, and all except one soil type overlay igneous bedrock (Soil Service Staff 2012).

Sample plots were located within the Ponderosa Pine zone (Franklin and Dyrness 1988). Typical overstory plants are ponderosa pine and Douglas-fir. Understory plants were dominated by bitter brush (*Purshia tridentata*), snowbrush ceanothus (*Ceanothus velutina*), several grasses (e.g., *Festuca idahoensis*), and bracken fern (*Pteridium aquilinum*). *Pinus ponderosa*/*Pursia tridentata* is the dominant plant association (Franklin and Dyrness 1988).

Low intensity surface fires were common in this forest type prior to fire suppression (Agee 1993). Fire has been infrequent in the area since 1910 and fire scars were encountered infrequently and plots were not located in areas that had signs of recent fire (e.g., charring at the base of trees). The

forest around Glenwood is largely second or third growth forest regenerating from high-grading of ponderosa pine or clearing for pasture. A few remnant old-growth ponderosa pine remain. WA-DNR actively manages the forest for timber production. Stands are also periodically leased for cattle grazing.

### *Study Design*

Thirty paired sample plots were surveyed around Glenwood, Washington in July and August, 2011 to determine the effect of *Armillaria* on forest structure and FCCS (Figure 2). Plots were paired based on WA-DNR Forest Management Units (FMUs) in an attempt to limit variability in measured variables due to differences resulting from management history and geography. FMUs are administrative units at which WA-DNR conducts management activities. A random point was selected in each FMU, and the nearest closed canopy forest was identified on aerial photography. If this point had another obvious disturbance (e.g., recent fire) a new point was randomly assigned. This point was surveyed as the “healthy” plot (Figure 3A). It was paired with a “diseased” plot center (Figure 3B). The diseased plot was randomly assigned in the closest significant *Armillaria* mortality center along a random compass bearing from the healthy plot. If no *Armillaria* mortality was found in the FMU along that bearing, another random bearing was assigned.

Referring to plots as “healthy” and “diseased” in this study is simply a convenience. Roth et al. (1980), working in the Glenwood area, found 43% root infection by *Armillaria* in stands they had determined to be lightly infected and 84% in heavily diseased areas. This suggests that *Armillaria* is prevalent in most locations. My plots may be better termed “non-symptomatic” and “symptomatic,” but for convenience of communication I have chosen to call them “healthy” and “diseased.”

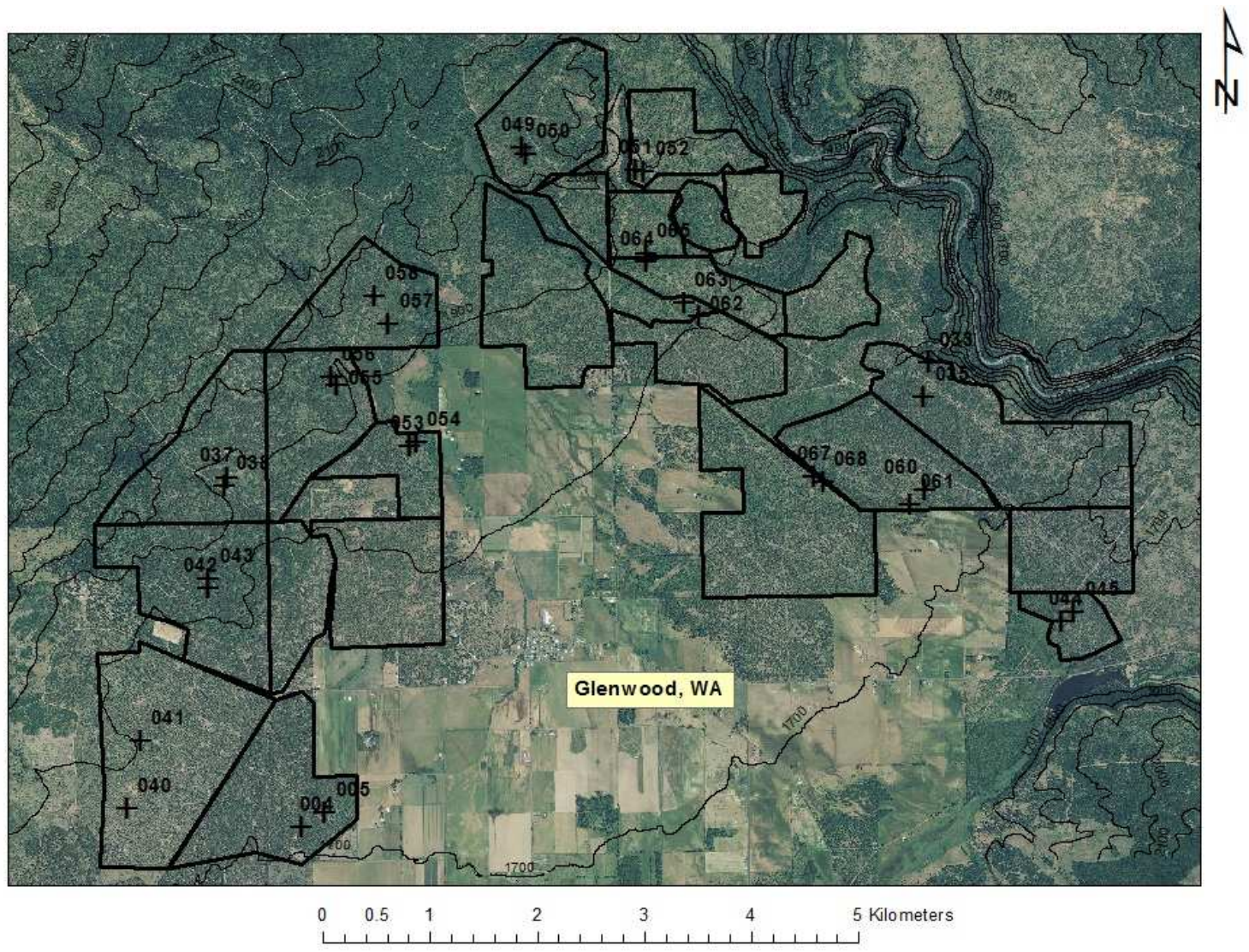


Figure 2. Map of plot locations (crosses) and number; sample units outlined in black; and 100 foot contour lines.



Figure 3. Examples of (A) “Diseased” non-symptomatic plot in ponderosa pine stand, and (B) “Healthy” plot in *Armillaria* disease center show typical disease symptoms.

#### *Field Measurements*

Each survey plot consisted of several nested sub-plots (Figure 4) sharing a common center point. The following data were recorded in each 1/10 acre (0.04 ha) circular plot: location, slope, aspect, elevation, and canopy cover by densitometer. For trees greater than 3 inches (7.6 cm) diameter at breast-diameter at breast-height (DBH), species, crown condition, and root disease symptoms (chlorotic needles, thin crowns, short new growth, stress cones) were recorded. Top height and canopy base height of a maximum of 3 representative overstory and midstory trees were measured using a clinometer. Snags were assessed for decay class (FCCS Field Sampling Guide 2010), and presence or absence of *Armillaria* signs (e.g., mycelial fans or rhizomorphs). Stump diameter, whether it was cut or not, and presence or absence of *Armillaria* signs were also recorded.

The percent cover of shrubs, average height, and the percent of dead material on each plant were recorded separately for each quadrant of a 20 ft (6.1 m) radius plot. Ladder fuel hazard was assessed in a 40.3 ft (12.6 m) radius plot (Figure 4) (Menning and Stephens 2007). Woody fuels were

assessed on 6 evenly spaced 50 ft (15.2 m) transects radiating from the plot center (Figure 4) using the method described by Brown (1974). Herbaceous and ground cover percent cover were estimated in 1

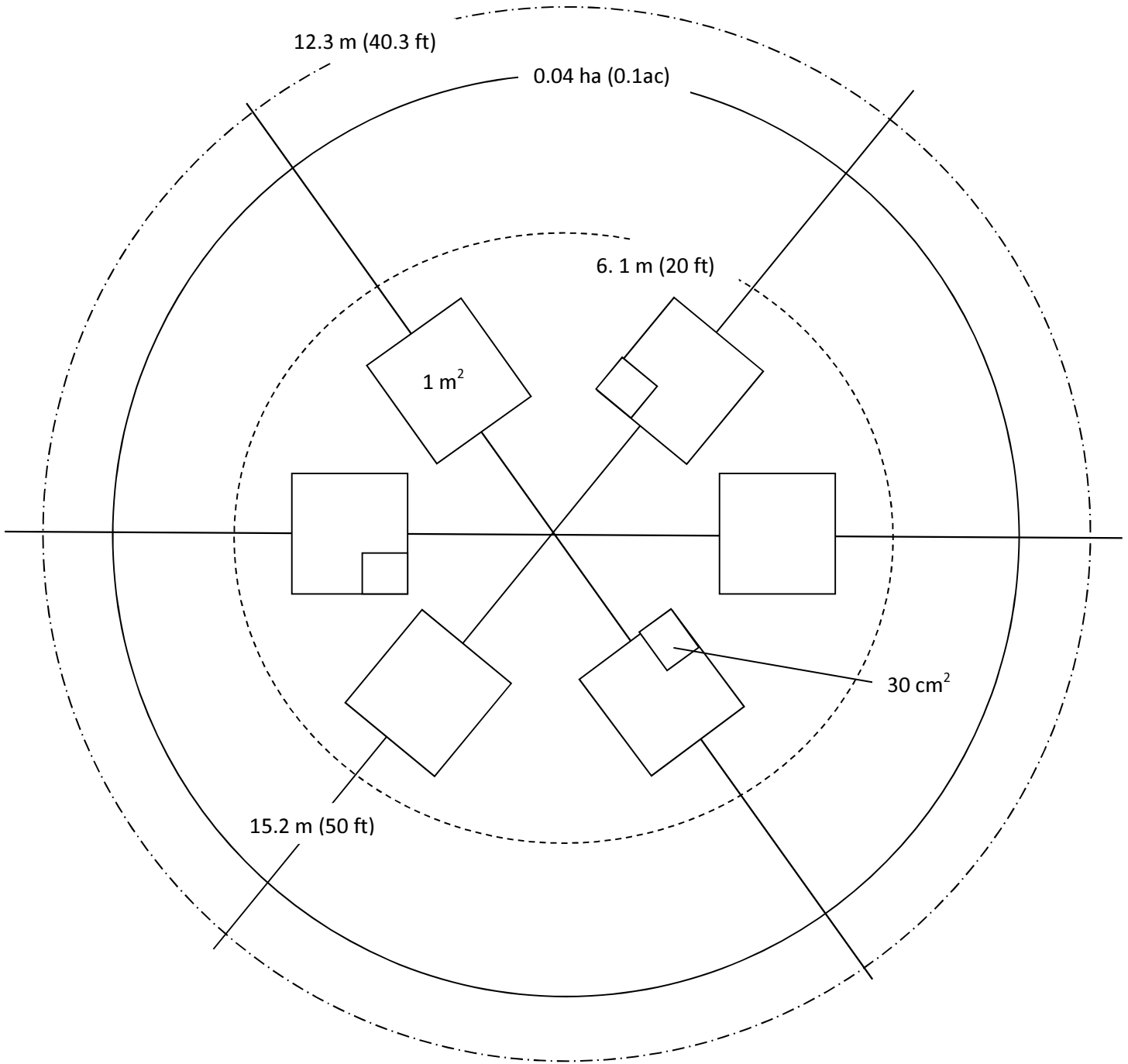


Figure 4. Sampling plot layout- not to scale. Subplots are referenced by their dimensions.

m<sup>2</sup> plots centered at 12 feet (3.7 m) along each fuel transect. Litter layer measurements and collections were made in 30 cm<sup>2</sup> subplots of every other m<sup>2</sup> herb plot, for a total of 3 subplots per larger plot. Five measurements each of litter and duff depth were recorded to nearest mm for each litter collection. Litter and duff collections were placed in airtight plastic bags for later laboratory analysis.

#### *Lab Analyses*

Litter and duff samples were stored in refrigerator at 3°C until weighed in the lab. Subsamples were weighed and then dried at least 48 h at 68°C in a drying oven in the School of Environmental and Forest Sciences, University of Washington. They were then weighed again to estimate their moisture content. The weight of the original sample was then corrected by the moisture content to obtain the dry weight.

#### *Fuel Loading Calculations*

Plot means were first calculated for variables, such as dead fuel loadings, where multiple surveys were conducted at each plot. The means should approach a normal distribution even if underlying data are not normal. Fuel loading data were calculated from surveys using the method described by Brown (1974).

#### *Statistical Analysis*

One-way paired *t*-tests with an alpha-level of 0.05 were used to test all data except where noted. Standard *t*-tests were used to test variables such as snag class diameters which had few paired observations (Zar 2010). A Chi-Squared test was used to test the proportion of Menning and Stephens' (2007) ladder fuel hazard classes between diseased and healthy plots. For *p*-values >0.05 the individual and combined means are given for reference, but the combined mean were used for modeling.

### *Fire Behavior Modeling*

The FCCS model was used to assess differences in potential fire behavior. Two custom fuelbeds were developed using data from the field surveys, one for diseased plots and one for healthy plots. The combined means of diseased and healthy plots were used to create the fuelbeds where no significant differences were detected. However, where significant differences were detected the appropriate mean was entered into the fuelbed (for  $\alpha < 0.05$ ). Species whose average relative cover was less than 1% for overstory, midstory and shrubs, or 20% for herbs were not included in fuelbeds. Twenty percent was used as a cut-off for herbs because of inconsistency in data-collection and because FCCS does not make strong distinctions in fire behavior potential between many herbaceous species. Because of the exclusion of species, mean relative cover was increased proportionally to facilitate relative covers summing to 100% in some cases. This is a requirement of the model. These changes were applied as evenly as possible to healthy and diseased fuel models. *Festuca spp.* was chosen to represent the unknown graminoids and *Achillea millefolium* to represent the unknown herbs in the model. Individuals of this genus and species were commonly observed on the plots. The actual data used for modeling are presented in Appendix A.

FCCS divides 1000 hr fuels into three sub-classes based on diameter. My analysis of 1000 hr fuels did not make that distinction. To facilitate fuelbed development the relative frequencies of the sub-classes were determined for sound and rotten fuels across all plots. These relative frequencies were multiplied by the overall 1000 hr fuel loadings to determined values for the sub-classes.

Where data were not available FCCS v2.1 default settings for “Pacific ponderosa pine -- Douglas-fir forest” were used. This fuelbed is an example of a ponderosa pine dominated forest in the Pacific Northwest and the Rocky Mountains. FCCS default fire weather parameters D2L2C3, the default for the “Pacific ponderosa pine -- Douglas-fir forest” type were held constant for both model runs.

Parameters are: woody fuel moistures (1-hr 6%, 10-hr 7%, 100-hr 8%, and 1000-hr 12%), live fuel moistures ( herbs 60%, shrubs and tree canopy 90%), duff moisture 50%, slope 0%, and midflame windspeed (6.4 kph).

## Results

### *Vegetation Characteristics:*

#### *Overstory Layer*

Total canopy cover in the overstory layer was significantly lower ( $p = 0.001$ ) in diseased plots (53 %) than in healthy plots (78%) (Table 1), a 25% reduction. However, there were no significant differences in species' relative cover as ponderosa pine was the dominant overstory tree in all plots (92% relative cover) (Table 1). Douglas-fir accounted for only 7% of the relative cover, while lodgepole pine and grand fir represented only 1% each. Overall stem density was significantly lower in diseased plots (125/ha) than in healthy plots (310/ha) ( $p=0.003$ ) as was tree height (23.9 versus 28.5 m,  $p=0.008$ ) (Table 1). However, there were no significant differences in height to live crown ( $p=0.1$ ) between diseased and healthy plots; the combined mean was 10.6 m. There was also no difference in mean DBH, which had a combined mean of 40.8 cm.

#### *Midstory Layer*

In the midstory there were no significant differences in species' relative cover in diseased and healthy plots (Table1). Ponderosa pine was the dominant species (84%) as it was in the overstory (92%). Douglas-fir contributed 15%, slightly greater (11% more) than in the overstory (7%) (Table 1). Tree height and DBH were also not significantly different and averaged 10 m and 16.6 cm, respectively. However, height to live crown (3.2 versus 5.6 m) and stem density (259 versus 106/ha) were significantly lower in diseased than in healthy plots ( $p=0.014$  and  $p=0.022$ , respectively) (Table 1).

### *Shrub Layer*

No differences in shrub structure or composition were detected between diseased and healthy plots (Table 1). Shrub percent cover averaged 18.7%, and had a mean height of 1.2 m. Bitterbrush (*Purshia tridentata*) and snowbrush ceanothus (*Ceanothus velutina*) were the dominant shrubs, average relative cover of 21 and 17%, respectively. Ponderosa pine occurred commonly in the shrub layer. Other shrubs were less common (Table 1). There was a high proportion of live to dead shrub material (87.9%).

### *Herbaceous Layer*

Overall 37 species were observed in the herbaceous layer (Appendix X). However, many were observed very infrequently. There was significantly higher herbaceous cover ( $p=0.038$ ) in diseased plots (33%) than healthy plots (23%). Graminoids were the dominant cover and were significantly higher ( $p=0.048$ ) in the diseased plots than in healthy plots (49% versus 36%). Herbaceous plants tended to have lower relative cover in diseased plots, but the difference was not significant ( $p=0.065$ ) (Table 1).

Table 1. Live plant characteristics in the overstory, midstory and herb layers in *Armillaria* infected (diseased) and healthy ponderosa pine forests. Data from diseased and healthy plots were compared using pairwise t-tests on 14 degrees of freedom (df) except where noted. \*No statistical test performed. <sup>1</sup> 13 df, <sup>2</sup> 12 df, <sup>3</sup> 9 df. Combined means are given only where p-values were >0.05.

Variable	Diseased	Healthy	p-Value	Combined Mean
Overstory				
Total canopy cover (%)	53	78	0.001	-
Relative species cover (%)				
<i>Pinus ponderosa</i>	90	93	0.19	92
<i>Pseudotsuga menziesii</i>	5	9	0.15	7
<i>Pinus contorta</i>	0	2	0.17	1
<i>Abies grandis</i>	1	0	0.1	1
Height (m)	23.9	28.5	0.008	-
Height to live crown (m)	10	11.2	0.1	10.6
Density (trees/ha)	125	310	0.003	-
Average DBH (cm)	40.1	41.6	0.36	40.8
Midstory				
Relative species cover (%)				
<i>P. ponderosa</i> <sup>3</sup>	78	90	0.092	84
<i>P. menziesii</i> <sup>3</sup>	20	9	0.086	15
<i>P. contorta</i> <sup>3</sup>	0	0	0.171	0
<i>A. grandis</i> <sup>3</sup>	0.4	0.4	0.101	0.4
Height (m)	8.4	11.5	0.054	10
Height to live crown (m)	3.2	5.6	0.014	-
Density (trees/ha)	106	259	0.022	-
Average DBH (cm) <sup>2</sup>	16.4	16.8	0.33	16.6
Shrubs				
Total cover (%)	17.8	19.6	0.31	18.7
Relative species cover (%)				
<i>P. ponderosa</i>	23	27	0.38	25
<i>Purshia tridentata</i> *	21	21	-	21
<i>Ceanothus velutina</i> *	17	17	-	17
<i>A. grandis</i>	5	15	0.38	10
<i>P. menziesii</i> *	6	9	-	8
<i>Spirea sp</i>	9	1	0.17	5
<i>Holodiscus discolor</i> *	7	0	-	3
<i>Corylus cornuta</i> *	1	4	-	3
<i>Salix sp</i> *	1	3	-	2
<i>Symphoricarpos albus</i> *	2	1	-	1

<i>Table 1 continued</i>				
Height (m)	1.37	1.02	0.27	1.2
Percent living (%) <sup>1</sup>	86.2	89.6	0.2	87.9
	Herbs			
Total cover (%)	33	23	0.038	-
Relative species cover (%)				
Graminoids	49	36	0.048	-
<i>Pteridium aquilinum</i>	24	23	0.465	24
Herbs	19	29	0.065	24

### *Fuel Characteristics:*

#### *Ground Fuels*

Ground fuels were designated as 1 hr (0-0.25 in. [0-0.6 cm] diam.); 10 hr (0.25-1 in. [0.6-2.5 cm] diam.); 100 hr (1-3 in. [2.5-6.7 cm] diam.); and 1000 hr (> 3 in. [6.7 cm] diam.) sound, rotten, and total. Ten-hr and 100-hr fuels had the most biomass in both diseased and healthy plots (Table 2) with the highest fuel loading being 6.94 Mg/ha in the 100 hr fuel category in diseased plots. One hr and 10 hr fuel loadings tended to be greater in diseased plots than healthy plots, but differences were not significant. However, significantly higher 100 hr (6.94 versus 2.45 Mg/ha,  $p=0.008$ ) and total 1000 hr (1.61 versus 0.67 Mg/ha,  $p=0.004$ ) fuel loadings were observed in diseased plots. Sound 1000-hr fuel loadings were also significantly greater (1.20 versus 0.21 Mg/ha) in diseased plots ( $p=0.004$ ), but there was no significant difference detected in rotten 1000-hr fuels, which had a combined mean of 0.43 Mg/ha. Sound and rotten fuel particles in the 7.6-23 cm diameter 1000-hr fuel subclass were observed most frequently (Table 3).

Table 2. Dead woody ground fuels, snags and ground cover in *Armillaria* infected (diseased) and healthy plots. All data were tested using pairwise t-tests using 14 degrees of freedom (df) except where noted. Combined means are given only where p-values are >0.05. <sup>1</sup> Standard two sample t-test (one-way) performed; the number of observations for each mean is given in parentheses; the weighted mean is given.

Variable	Diseased	Healthy	p-value	Combined Mean
Woody Fuels				
1hr [0-0.6 cm] (Mg/ha)	0.5	0.28	0.22	0.39
10hr [0.6-2.5 cm] (Mg/ha)	2.69	2.1	0.2	2.4
100hr [2.5-6.7 cm] (Mg/ha)	6.94	2.45	0.008	-
1000hr all [>6.7 cm] (Mg/ha)	1.61	0.67	0.004	-
1000hr sound [>6.7 cm] (Mg/ha)	1.2	0.21	0.004	-
1000hr rotten [>6.7 cm] (Mg/ha)	0.46	0.41	0.38	0.43
Snags				
Class 1 (with foliage) - density (No./ha)	9.9	6.6	0.32	8.2
- average DBH. (cm) <sup>1</sup>	17.5 (4)	11.8 (2)	0.21	15.6
Class 1 - w/o foliage - density (No./ha)	19.8	19.1	0.47	19.4
- average DBH (cm) <sup>1</sup>	15.7 (4)	13.6 (5)	0.28	14.5
Class 2 - density (No./ha)	44	3.3	0.003	-
- average DBH (cm) <sup>1</sup>	28.1 (11)	9.7 (1)	0.11	26.6
Class 3 - density (No./ha)	23.3	4.9	0.046	-
- average DBH (cm) <sup>1</sup>	23.9 (6)	12.6 (2)	0.09	21.1
Ground Cover				
Litter depth (cm)	3.3	3.1	0.378	3.2
Litter mass (Mg/ha)	2.3	3.7	0.004	-
Total litter cover (%)	76.7	93.2	0.002	-
Relative litter cover (%)				
Long needle litter	72	93	0.0003	-
Grass litter	18	3	0.025	-
Broadleaf litter	8	4	0.024	-
Short needle litter	3	0	0.17	1

Table 3. Percent of rotten and sound 1000 hr fuels found in each diameter subclass.

Diameter Class (cm)	Sound	Rotten
7.6-23	86	91
23-51	14	9
>51	0	0

Litter cover was significantly lower in diseased plots (76.7%) than healthy plots (93.2%) ( $p=0.002$ ) (Table 2). Long ponderosa pine needles were the dominant type of litter and had significantly less relative cover in diseased plots (72%) than in healthy plots ( $p=0.0003$ ) (Table 2). Cured grass litter was far less abundant than needles, but represented significantly more of the relative cover in diseased plots (18% versus 3%). Broadleaf litter also had a significantly higher relative cover in diseased plots (8% versus 4%), but was not a large contributor to ground cover in either plot type. There was no significant difference in short needle cover provided by Douglas-fir or grand fir between plot types. Litter depth was not significantly different between healthy and diseased plots (the combined was 3.2 Mg/ha), but litter mass was significantly lower in diseased plots (2.3 versus 3.7 Mg/ha,  $p=0.004$ )(Table 2). In general litter mass was lower than the combined total of 1 hr to 1000 hr woody fuels.

#### *Standing Dead Trees*

There were no significant differences in density of the most recently dead- class 1 snags (with and without foliage) between plot types. The combined mean densities were 8.2/ha and 19.4/ha, respectively (Table 2). However, diseased plots had a significantly greater density compared to healthy plots of older class 2 snags (44/ha versus 3.3/ha) and class 3 snags (23.3/ha and 4.9/ha) . There were no significant differences in the average diameters within snag classes between diseased and healthy plots (Table 2) and mean DBHs ranged from 14.5 to 26.6 cm.

#### *Ladder Fuels*

Using Chi-squared analysis a significant difference ( $p<0.01$ ) in the distribution of Menning and Stephens' (2007) ladder fuel hazard or risk classes was detected between diseased and healthy plots (Table 4). These classes are A (high risk with clumped fuels and continuous ladder); B (moderate risk with clumped fuels and discontinuous ladder); C ( moderate risk with ladder but no clumping of low aerial fuels); D (low risk with no clumping and no ladder); and E (no risk with no canopy present).

However, this difference was due overwhelmingly to differences at the low risk end of the hazard classes. The partial chi-squared for class D low (10.12) and class E no-canopy class (16.00) accounted for 99% of the total chi-squared. There was no difference between diseased and healthy plots in classes A, B and C.

Table 4. Menning and Stephens' (2007) ladder fuel hazard classes in healthy and diseased plots. The total chi-squared is significant at  $p < 0.01$ .

Group	A	B	C	D	E	No. observations	Total Chi- squared
Diseased	12	16	9	7	16	60	-
Healthy	11	16	8	25	0	60	-
Expected	11.5	16	8.5	16	8	-	-
Diseased and Healthy Partial Chi-squared	0.04	0.0	0.0	10	16	120	26.22

Diseased plots had 16 occurrences of Class E “no canopy,” while healthy plots had none. There were 25 occurrences of Class D “low” ladder fuel hazard in healthy plots, but only 7 in diseased plots. Numbers in classes A, B and C (high or moderate ladder fuel hazard) were similar in diseased and healthy plots. Ladder fuels were turned off in the fire behavior modeling runs, because of the lack of differences in classes A, B and C, and incompatibility of field data with required FCCS inputs.

#### *Potential Fire Behavior*

The Fuel Characteristics Classification System (FCCS) fire potentials provide an “index of the intrinsic capacity of each fuelbed to support surface fire behavior, crown fire behavior, and provide fuels for flaming, smoldering, and residual consumption” (Ottmar et al. 2007). FCCS also provides classical predictions of Rate of Spread (ROS), flame length, and reaction intensity for surface fire behavior.

Surface fire behavior metrics were generally reduced in the diseased fuelbed (Table 5). The surface fire potential, “calculated as the maximum of spread potential and flame length potential...” (FCCS v2.1) was lower in diseased than the healthy fuelbed (Table 5). This is illustrated by the surface fire ROS being lower in the diseased (1.4 m/min) than healthy fuelbed (1.9 m/min). The flame length

was also reduced in the diseased fuelbed compared to the healthy (1 m/min versus 1.2 m/min).

Reaction intensity, however, is greater in the diseased fuelbed than the healthy (882 kW/m<sup>2</sup> versus 824 kW/m<sup>2</sup>).

Crown fire behavior metrics were also lower in the diseased fuelbed. Initiation, crown-to-crown transmissivity, and spread potentials were all lower in the diseased fuelbed. Overall crown fire potential, a weighted average of the subpotentials, was also lower in the diseased fuelbed (Table 5).

Available fuel potential is the sum of the loading of fuels available for consumption in the various phases of combustion and is given in units of Mg/ha in Table 5. Less fuel was available in the initial flaming phase of combustion in diseased plots (47 versus 63 Mg/ha) with more left for the smoldering (14 versus 11 Mg/ha) and residual smoldering (16 versus 7 Mg/ha) combustion phases (Table 5).

Table 5. Fuel Characteristics Classification System (FCCS) predictions of surface fire, crown fire and available fuel potentials for diseased, healthy, and reference fuelbeds . Potentials are given on a 0-9 scale. <sup>1</sup>These potentials are defined in the methods. <sup>2</sup>These are the suggested crosswalks to Scott and Burgan (2005) fuel models; the original 13 fuel models (Rothermel 1972, Albini 1976) are in parenthesis. <sup>3</sup> Values are in units of 22.4 Mg/ha.

<b>Fire Behavior Prediction</b>	<b>Diseased</b>	<b>Healthy</b>	<b>FCCS Standard</b>
<b>Surface fire potential<sup>1</sup></b>	4	5	6
Reaction potential	5.5	5.3	4.7
Reaction intensity (kW/m <sup>2</sup> )	882	824	644
Spread potential	4.2	5	6
Rate of spread (m/min)	1.4	1.9	2.7
Flame length potential	3.7	4	3.7
Flame length (m)	1	1.2	1.1
Fuel model crosswalks <sup>2</sup>	TL8 (9)	TL9 (9)	TU2 (9)
<b>Crown fire potential<sup>1</sup></b>	3	4	4
Initiation potential	2.4	2.5	3.5
Transmissivity potential	6.3	8.7	7.2
Spread potential	2.2	3.2	2.7
<b>Available fuel potential<sup>1,3</sup></b>	3	4	3
Flame available fuel <sup>3</sup>	2.1	2.8	2
Smoldering available fuel <sup>3</sup>	0.6	0.5	0.7
Residual fuel <sup>3</sup>	0.7	0.3	0.6

## Discussion

### *Vegetation characteristics in Armillaria infected and healthy ponderosa pine forests*

*Armillaria* root disease has changed the vegetation characteristics in the ponderosa pine forests of the study area. The most noticeable change was a reduction in overstory canopy cover in diseased areas (53%) compared to healthy areas (92%) because of *Armillaria* caused mortality and the creation of canopy gaps. However, there were no changes in species' relative cover. Ponderosa pine was the dominant tree species (92%) followed by Douglas-fir (7%), while grand fir and lodgepole pine were barely present. As expected with lack of recent fires Douglas-fir had a greater representation in the midstory tree layer (15%) while ponderosa pine was reduced to 84%. *Phellinus* root disease in Douglas-fir and mountain hemlock in Oregon causes similar mortality gaps and changes the overstory and midstory species composition (Holah et al. 1993; 1997). However, I found few differences in the shrub and herb layers. It may be that water limits shrub and herb establishment and growth in the Glenwood area more than light. Thus the increased light environment in *Armillaria* mortality centers probably has little positive effect on herb and shrub growth.

In a study of insect defoliation on potential wildfire behavior in grand fir a few kilometers from this study and 200 m higher in elevation, Hummel and Agee (2003) predicted increased shrub and herb fuels as a result of reduced canopy cover. However, I found few differences except higher herbaceous cover in diseased plots with more of that cover being made up of grasses. Naumburg and DeWald (1999) found that changes in forest structure influenced graminoid species composition in ponderosa forests of the White Mountains of Arizona. However, I did not determine graminoids to the species level as resources were limited and detecting differences in herb community composition was not a primary objective. However, there may be differences in the shrub and herb community composition influenced by root diseases. Other studies (e.g. Holah et al. 1997) have shown an effect of root disease on plant community composition. This study does not show any strong evidence to support this

effect in low elevation, dry ponderosa pine forest. However, the field methods of this study were not intended to detect small differences in community composition. More rigorous field methods would be needed to get a better understanding of the effect of root disease on herbaceous and shrub communities.

Furthermore anecdotal observations show that the effect of root disease on understory communities in dry ponderosa pine sites is less dramatic than is commonly seen in moister western Washington forests (pers. obs.). Shrub and herb communities in the wetter, darker west-side forests may be more limited for light than communities in drier, higher-light east-side ponderosa pine forests. If that is the case, then root diseases, which create canopy gaps and increase light availability to the understory, may cause greater change in the vegetation communities of west-side forests.

#### *Fuel characteristics in Armillaria infected and healthy ponderosa pine forests*

All woody fuel classes were detected at higher levels in the diseased plots, however, only differences in larger diameter classes were significant. Lundquist (2007) found similar, but slightly lower, dead woody fuel loadings in 45 stands infected with *Armillaria* in the Black Hills of South Dakota. Others have also detected differences only in the largest diameter fuel classes in plots with root disease (Fields 2003) and mistletoe infection (Hoffman et al. 2007). This may be due to sampling methodology; small diameter fuels may be more clumped at a smaller scale (e.g., at the scale of a fallen branch) than large diameter fuels (e.g., at the scale of a 0.1 ha *Armillaria* mortality center).

The litter depths reported by Lundquist (2007) were similar to my study. Litter weight and depth in my study for diseased plots (3.7 Mg/ha and 3.1 cm, respectively) were at the low end of the range reported (3.7-125.2 Mg/ha and 2-16 cm respectively) for ponderosa pine in Sequoia National Park, CA

(Stephens et al. 2004). However, these California forests are likely more productive than the Glenwood site.

The Stephens and Menning (2007) ladder fuel method is useful for identifying differences in ladder fuel hazard between groups of plots. It is quick to implement in the field. However, it does not provide all the input which is necessary to model crown-fire in FCCS. A field method that would yield appropriate ladder fuel data for FCCS would be useful.

*Forest structure as a determinant of potential surface fire behavior.*

The reduction in predicted surface fire flame length and rate of spread in the diseased fuelbed is modest but noteworthy. Differences in woody fuels and surface litter largely account for differences seen in surface fire behavior. Greater loading of large diameter fuels in the diseased fuelbed increased reaction intensity but also increased the heat sink term in the equation used to calculate ROS and flame length. In other words large woody fuels initially absorb much of the energy released in flaming combustion thereby slowing ROS and decreasing flame length. Increased fuel loading does not mean increased fire behavior when much of that increase is due to large diameter fuels. Studies which have documented increased fuel loads of large diameter woody fuels (e.g., Fields 2003, Hoffman et al. 2007) do not acknowledge this heat-sink effect in determining the potential effect of increased fuel loading on fire behavior.

Decreased long ponderosa pine needle litter cover and loading were detected in diseased plots. This is likely due to decreased litter inputs because of lower density of ponderosa pine in the overstory of diseased plots. Needles are the primary carrier of fire in the Timber-Litter 8 and 9 fuel models (Scott and Burgan 2005). An increase in grass litter cover, likely due to a higher light environment or greater water availability in disease centers, did not compensate for decreased needle litter.

Smoldering and residual smoldering potentials are increased in diseased plots due to increased large diameter woody fuels. This has several implications. First, a smoldering fire with a long dwell-time

can have a greater ecological impact on nearby soils and plants than a quick moving flaming front (Agee 1993). Operationally, smoldering fuels provide a source for re-ignition if the initial combustion leaves a patchy mosaic of burned and unburned fuels. These smoldering “heavy” fuels can be time consuming during mop-up. Second, smoldering fuels continue to produce smoke which may impact air quality for nearby communities.

In the design phase of this study I hypothesized that shrubs and herbs may exploit the high-light environment created by the *Armillaria* mortality center. No increases in shrub cover, or changes in shrub community composition were detected as a result of root disease. Slightly greater herbaceous cover was detected in diseased plots as well as differences in composition. The lack of large detected differences in shrubs and herbs is likely because moisture and not light is the factor that most limits establishment and growth in these forests. Shrub and herb layer differences may be more profound in wetter forested areas (e.g., Holah et al. 1993; 1997, Hummel and Agee 2003), and could have a large effect on both surface and crown fire behavior.

*Forest structure as a determinant of potential crown fire behavior.*

While the interpretation of *Armillaria* effects on surface fire is somewhat nuanced, the effect of *Armillaria* on crown fire is straight-forward. *Armillaria* reduces overstory and midstory tree density which reduces the potential for fire to transfer from crown to crown thereby reducing the potential for spread of crown fires. There was no increase in hazardous ladder fuels detected in diseased plots as has been suggested (e.g., McDonald et al. 2005). This may be due to management activities which have kept Douglas-fir encroachment to a minimum. However, current FCCS ladder fuel inputs are currently limited to a yes/no decision on the vertical continuity of ladder fuels and the type of ladder fuel present. This is an oversimplification. The proportion of a stand with vertically continuous fuels and the extent to which fuels are continuous likely play important roles in transitioning surface fire to canopy fire.

There are several ways which *Armillaria* may impact fire behavior which were outside the scope of this study. Canopy gaps caused by *Armillaria* may have a hotter, drier, and windier microclimate than surrounding healthy forest. Trees infected with *Armillaria* may have lower foliar moisture contents, thereby increasing torching and crown fire potential. However, infected trees and groups of trees tend to be isolated and scattered, and may not affect overall crownfire behavior of a stand. Further study of these variables may resolve these questions.

#### *Fire Modeling as a Tool for Investigating the Effect of Disease on Fire Behavior*

As Knight (1987) pointed out, disease and insects can affect fire behavior in many ways. A single disturbance can affect forest composition and structure in ways which may simultaneously increase and decrease potential fire behavior. For example, in this study diseased plots had higher grass litter cover and simultaneously lower needle litter cover. What would be the cumulative effect on fire behavior? Now introduce dozens of other variables which affect fire behavior (e.g., weather, fuel moisture, woody fuel loading) which can be affected by forest disturbances. Modeling gives the researcher an unbiased tool to attempt to discern the overall effect of the disturbance on fire behavior when multiple confounding effects are present.

#### *Conclusions and Future Study*

*Armillaria* has a large impact on the structure of managed forest stands around Glenwood, Washington. It primarily reduces canopy cover and tree density, increases large diameter dead woody fuels, and increases numbers of older snags. The composition of the plant community is largely unaffected, but there are small differences in the herbaceous layer. This modest effect on composition may be due in part to the relatively few species, especially tree species, which can survive in these low-elevation dry forests.

From a fuels-perspective, *Armillaria* reduces available canopy fuels by reducing stem density, and has no measureable impact on ladder fuel abundance or ground fuel heights, and only a modest

effect on canopy base height. *Armillaria* did, however, increase older age class snags. *Armillaria* increased fuel loads of larger diameter woody fuels, with no effect on smaller diameter fuels. Needle litter, the primary carrier of surface fire in this forest type, was greatly reduced in *Armillaria* plots. However these plots had a slight increase in grass cover, another carrier of fire. Overall the threat of fuels was reduced in *Armillaria* infected plots.

This study demonstrates that the effect of forest disturbances on fire behavior is complex. Disturbances largely affect forest structure, but also composition, which in turn affect fire behavior. Not only can they cause changes which are obvious to the casual observer, for example, reducing overstory tree density, but they may also cause more subtle changes, like changing the microclimate or reducing needle litter loads. These changes can have contradictory effects on fire behavior. Fire behavior modeling provides an unbiased way to examine the relative importance of the many changes in structure and composition that a forest disturbance may cause.

The results of this study are only applicable to the scale, forest type, and locality where the study was conducted; managed stands of ponderosa pine near Glenwood, Washington. Nearby unmanaged fir-dominated stands at higher elevations with different fire regime may be affected very differently, and ponderosa pine stands in other areas may respond differently. However, there are important insights from this study that may be of use for future investigations. First this study demonstrates that any investigation into the effect of disease on fire must include fire behavior modeling or actual fire severity data. Simply measuring a few structural variables as an indicator of potential fire behavior is insufficient to provide a realistic, reliable picture of fire behavior. Second this study calls into question the long-held belief that root diseases increase potential fire behavior. Third the stand scale results of this study provide a starting point for landscape scale assessment of the impact of root disease on potential fire behavior.

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Appendix A. Data used for FCCS fire behavior modeling- Diseased Fuelbed

<b>FUELBED INPUT REPORT</b>
<b>Author:</b>
<b>Date:</b> Feb 7, 2012
<b>Fuelbed number:</b> 24
<b>File Name:</b>
<b>Data quality ranking:</b>
<b>Description:</b> diseased sites, finalized

**CANOPY - TREES**

Input variable	All trees	Trees - overstory	Trees - midstory	Trees - understory
Total percent cover (%)	53.0 ( 30.00 / 85.00 )	53.0 ( 10.00 / 60.00 )	20.0 ( 0.00 / 40.00 )	
Height ( m )		23.9 ( 18.3 / 39.6 )	10.0 ( 12.2 / 30.5 )	
Height to live crown ( m )		10.6 ( 6.1 / 19.8 )	3.2 ( 1.5 / 16.8 )	
Density (#/ha)		20.5 ( 6.1 / 28.3 )	17.4 ( 0.0 / 40.5 )	
Dbh ( cm )		40.8 ( 38.1 / 88.9 )	16.4 ( 25.4 / 63.5 )	
Species (relative cover %)		Pinus ponderosa (92.00) Pseudotsuga menziesii (7) Pinus contorta (1)	Pinus ponderosa (84) Pseudotsuga menziesii (15) Abies grandis (1) Pinus contorta (0.4)	

**CANOPY - SNAGS**

Input Variable	Snags - class 1 with foliage	Snags - class 1 without foliage	Snags - class 2	Snags - class 3
Height ( m )	12.2 ( 1.5 / 30.5 )		10.7 ( 1.5 / 27.4 )	6.1 ( 1.5 / 21.3 )
Density (#/ha)	1.3 ( 2.0 / 12.1 )	3.2 ( -1.2 / -1.2 )	7.2 ( 0.8 / 12.1 )	3.8 ( 0.8 / 12.1 )
Dbh ( cm )	15.7 ( 10.2 / 76.2 )	14.5 ( -7.6 / -7.6 )	26.6 ( 10.2 / 76.2 )	21.1 ( 25.4 / 76.2 )
Species (relative cover %)	Pinus ponderosa (100.00)	Pinus ponderosa (100)	Pinus ponderosa (100.00)	Pinus ponderosa (100.00)

Appendix A. Data used for FCCS fire behavior modeling- Diseased Fuelbed

<b>FUELBED INPUT REPORT</b> Author: Date: Feb 7, 2012 Fuelbed number: 24 File Name: Data quality ranking: Description: diseased sites, finalized
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**CANOPY - LADDER FUELS**

Input variable	Ladder fuels
Minimum height ( m )	
Maximum height ( m )	
Is there a vertical continuity between canopy and lower strata?	Yes
Ladder fuel type	0

**SHRUBS - NEEDLE DRAPE**

Input variable	Shrubs - needle drapes
Is needle drape sufficient to affect fire behavior?	No

Appendix A. Data used for FCCS fire behavior modeling- Diseased Fuelbed

<p>Click to go to the next page in the document</p> <p><b>FUEL</b>  <b>Author:</b>  <b>Date:</b> Feb 7, 2012  <b>Fuelbed number:</b> 24  <b>File Name:</b>  <b>Data quality ranking:</b>  <b>Description:</b> diseased sites, finalized</p>
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**SHRUBS AND NONWOODY FUELS**

Input variable	Shrub - primary layer	Shrub - secondary layer	Nonwoody fuels - primary layer	Nonwoody fuels - secondary layer
Percent cover (%)	18.7 (-3.00 /-3.00)		33.0 (20.00 /100.00)	
Height ( m )	1.2 ( -0.9 / -0.9 )		0.1 ( 0.1 / 0.5 )	
Percent live (%)	87.9 (-3.00 /-3.00)		75.00 (40.00 /95.00)	
Loading ( Mg/ha )			1.1 ( 0.0 / 2.2 )	
Species (relative cover %)	Pinus ponderosa (27) Purshia tridentata (23) Ceanothus velutinus (18) Abies spp. (18) Spiraea douglasii (5) Holodiscus discolor (3) Corylus comuta (3) Salix spp. (2) Symphoricarpos albus (1)		Festuca spp. (50) Pteridium aquilinum (25) Achillea millefolium (25)	

**WOODY FUELS - ALL DOWNED AND DEAD WOODY FUELS**

Input variable	All downed and dead woody fuel
Depth ( cm )	0.3 ( 0.0 / 2.4 )
Total percent cover (%)	25.00 (2.00 /50.00)

Appendix A. Data used for FCCS fire behavior modeling- Diseased Fuelbed

**FUELBED INPUT REPORT**

**Author:**  
**Date:** Feb 7, 2012  
**Fuelbed number:** 24  
**File Name:**  
**Data quality ranking:**  
**Description:** diseased sites, finalized

**WOODY FUELS - SOUND AND ROTTEN WOODY FUELS**

Input variable	Sound wood	Rotten Wood
0-0.635 cm ( Mg/ha )	0.4	N/A
0.635 - 2.54 cm loading ( Mg/ha )	2.4	N/A
2.54 - 7.62 cm loading ( Mg/ha )	6.9	N/A
7.62 - 22.86 cm loading ( Mg/ha )	1.0	0.4
22.86 - 50.8 cm loading ( Mg/ha )	0.2	0.0
> > 50.8 cm loading ( Mg/ha )	0.0	0.0
Species (relative cover %)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)

**WOODY FUELS - STUMPS**

Input variable	Stumps - sound	Stumps - rotten	Stumps - lightered-pitchy
Density (#/ ha)	2.0 ( 2.0 / 4.0 )	8.1 ( 4.0 / 12.1 )	4.0 ( 0.8 / 16.2 )
Diameter ( cm )	22.9 ( 10.2 / 63.5 )	38.1 ( 10.2 / 101.6 )	88.9 ( 50.8 / 101.6 )
Height ( m )	0.3 ( 0.2 / 1.2 )	0.6 ( 0.2 / 0.9 )	0.6 ( 0.3 / 1.2 )
Species (relative cover %)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)

Appendix A. Data used for FCCS fire behavior modeling- Diseased Fuelbed

<b>FUELBED INPUT REPORT</b> <b>Author:</b> <b>Date:</b> Feb 7, 2012 <b>Fuelbed number:</b> 24 <b>File Name:</b> <b>Data quality ranking:</b> <b>Description:</b> diseased sites, finalized
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**WOODY FUELS - WOODY FUEL ACCUMULATIONS**

Input variable	Piles	Jackpots	Windrows
Density (#/ha)			
Diameter (cm)			
Height (m)			
Species (relative cover %)			

**LITTER LICHEN MOSS**

Input variable	Litter	Lichen	Moss
Depth (cm)	0.5 ( 0.2 / 0.6 )		
Percent Cover (%)	76.7 ( 60.00 / 95.00 )		
Litter arrangement/moss type	Normal	N/A	
Litter type (relative cover %)	Short needle pine      3.0 Long needle pine      72.0 Other conifer Broadleaf deciduous      8.0 Broadleaf evergreen Palm frond Grass                      17.0		

Appendix A. Data used for FCCS fire behavior modeling- Diseased Fuelbed

<b>FUELBED INPUT REPORT</b> <b>Author:</b> Date: Feb 7, 2012 Fuelbed number: 24 File Name: Data quality ranking: Description: diseased sites, finalized
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**GROUND FUELS - DUFF**

Input variable	Duff	Upper duff	Lower Duff
Percent Rotten	3.00 ( 0.00 / 20.00 )	N/A	N/A
Depth ( cm )	N/A	1.3 ( 0.5 / 3.6 )	0.3 ( 0.0 / 3.6 )
Percent Cover (%)	N/A	80.00 ( 40.00 / 90.00 )	80.00 ( 40.00 / 90.00 )
Derivation	N/A	Partially decomposed sphagnum or sedge	Fully decomposed sphagnum or sedge

**GROUND FUELS - SQUIRREL MIDDENS AND BASAL ACCUMULATIONS**

Input variable	Squirrel middens	Basal accumulations
Depth ( cm )		5.1 ( 3.8 / 10.2 )
Radius ( m )		0.3 ( 0.2 / 0.6 )
Density (#/ha)		N/A
Percent affected (%)	N/A	20.00 ( 0.00 / 75.00 )
Type	N/A	Bark slough

Appendix A. Data used for FCCS fire behavior modeling- Healthy Fuelbed

<b>FUELBED INPUT REPORT</b>
<b>Author:</b>
<b>Date:</b> Feb 7, 2012
<b>Fuelbed number:</b> 24
<b>File Name:</b>
<b>Data quality ranking:</b>
<b>Description:</b> healthy sites,finalized

**CANOPY - TREES**

Input variable	All trees	Trees - overstory	Trees - midstory	Trees - understory
Total percent cover (%)	78.0 ( 30.00 / 85.00 )	78.0 ( 10.00 / 60.00 )	20.0 ( 0.00 / 40.00 )	
Height ( m )		28.5 ( 18.3 / 39.6 )	10.0 ( 12.2 / 30.5 )	
Height to live crown ( m )		10.6 ( 6.1 / 19.8 )	5.6 ( 1.5 / 16.8 )	
Density (#/ha )		50.8 ( 6.1 / 28.3 )	42.4 ( 0.0 / 40.5 )	
Dbh ( cm )		41.0 ( 38.1 / 88.9 )	16.4 ( 25.4 / 63.5 )	
Species (relative cover %)		Pinus ponderosa (92.00) Pseudotsuga menziesii (7) Pinus contorta (1)	Pinus ponderosa (84) Pseudotsuga menziesii (15) Abies grandis (1) Pinus contorta (.4)	

**CANOPY - SNAGS**

Input Variable	Snags - class 1 with foliage	Snags - class 1 without foliage	Snags - class 2	Snags - class 3
Height ( m )	12.2 ( 1.5 / 30.5 )		10.7 ( 1.5 / 27.4 )	6.1 ( 1.5 / 21.3 )
Density (#/ha)	1.3 ( 2.0 / 12.1 )	3.2 ( -1.2 / -1.2 )	0.5 ( 0.8 / 12.1 )	0.8 ( 0.8 / 12.1 )
Dbh ( cm )	15.7 ( 10.2 / 76.2 )	14.5 ( -7.6 / -7.6 )	26.6 ( 10.2 / 76.2 )	12.3 ( 25.4 / 76.2 )
Species (relative cover %)	Pinus ponderosa (100.00)	Pinus ponderosa (100)	Pinus ponderosa (100.00)	Pinus ponderosa (100.00)

Appendix A. Data used for FCCS fire behavior modeling- Healthy Fuelbed

<p><b>FUELBED INPUT REPORT</b>  <b>Author:</b>  <b>Date:</b> Feb 7, 2012  <b>Fuelbed number:</b> 24  <b>File Name:</b>  <b>Data quality ranking:</b>  <b>Description:</b> healthy sites,finalized</p>
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**CANOPY - LADDER FUELS**

Input variable	Ladder fuels
Minimum height ( m )	
Maximum height ( m )	
Is there a vertical continuity between canopy and lower strata?	Yes
Ladder fuel type	0

**SHRUBS - NEEDLE DRAPE**

Input variable	Shrubs - needle drapes
Is needle drape sufficient to affect fire behavior?	No

Appendix A. Data used for FCCS fire behavior modeling- Healthy Fuelbed

<b>FUELBED INPUT REPORT</b> <b>Author:</b> <b>Date:</b> Feb 7, 2012 <b>Fuelbed number:</b> 24 <b>File Name:</b> <b>Data quality ranking:</b> <b>Description:</b> healthy sites,finalized
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**SHRUBS AND NONWOODY FUELS**

Input variable	Shrub - primary layer	Shrub - secondary layer	Nonwoody fuels - primary layer	Nonwoody fuels - secondary layer
Percent cover (%)	18.7 (-3.00 /-3.00)		23.0 (20.00 /100.00)	
Height ( m )	1.2 ( -0.9 / -0.9 )		0.1 ( 0.1 / 0.5 )	
Percent live (%)	87.9 (-3.00 /-3.00)		75.00 (40.00 /95.00)	
Loading ( Mg/ha )			0.8 ( 0.0 / 2.2 )	
Species (relative cover %)	Pinus ponderosa (27) Purshia tridentata (23) Ceanothus velutinus (18) Abies spp. (18) Spiraea douglasii (5) Holodiscus discolor (3) Corylus comuta (3) Salix spp. (2) Symphoricarpos albus (1)		Festuca spp. (42) Pteridium aquilinum (29) Achillea millefolium (29)	

**WOODY FUELS - ALL DOWNED AND DEAD WOODY FUELS**

Input variable	All downed and dead woody fuel
Depth ( cm )	0.3 ( 0.0 / 2.4 )
Total percent cover (%)	25.00 (2.00 /50.00)

Appendix A. Data used for FCCS fire behavior modeling- Healthy Fuelbed

<b>FUELBED INPUT REPORT</b>
Author:
Date: Feb 7, 2012
Fuelbed number: 24
File Name:
Data quality ranking:
Description: healthy sites,finalized

**WOODY FUELS - SOUND AND ROTTEN WOODY FUELS**

Input variable	Sound wood	Rotten Wood
0-0.635 cm ( Mg/ha )	0.4	N/A
0.635 - 2.54 cm loading ( Mg/ha )	2.4	N/A
2.54 - 7.62 cm loading ( Mg/ha )	2.5	N/A
7.62 - 22.86 cm loading ( Mg/ha )	0.2	0.4
22.86 - 50.8 cm loading ( Mg/ha )	0.0	0.0
> > 50.8 cm loading ( Mg/ha )	0.0	0.0
Species (relative cover %)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)

**WOODY FUELS - STUMPS**

Input variable	Stumps - sound	Stumps - rotten	Stumps - lightered-pitchy
Density (#/ ha)	2.0 ( 2.0 / 4.0 )	8.1 ( 4.0 / 12.1 )	4.0 ( 0.8 / 16.2 )
Diameter ( cm )	22.9 ( 10.2 / 63.5 )	38.1 ( 10.2 / 101.6 )	88.9 ( 50.8 / 101.6 )
Height ( m )	0.3 ( 0.2 / 1.2 )	0.6 ( 0.2 / 0.9 )	0.6 ( 0.3 / 1.2 )
Species (relative cover %)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)	Pinus ponderosa (80.00) Pseudotsuga menziesii (20.00)

Appendix A. Data used for FCCS fire behavior modeling- Healthy Fuelbed

<b>FUELBED INPUT REPORT</b> <b>Author:</b> <b>Date:</b> Feb 7, 2012 <b>Fuelbed number:</b> 24 <b>File Name:</b> <b>Data quality ranking:</b> <b>Description:</b> healthy sites, finalized
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**WOODY FUELS - WOODY FUEL ACCUMULATIONS**

Input variable	Piles	Jackpots	Windrows
Density (#/ ha)			
Diameter ( cm )			
Height ( m )			
Species (relative cover %)			

**LITTER LICHEN MOSS**

Input variable	Litter	Lichen	Moss
Depth ( cm )	0.5 ( 0.2 / 0.6 )		
Percent Cover (%)	93.2 ( 60.00 / 95.00 )		
Litter arrangement/moss type	Normal	N/A	
Litter type (relative cover %)	Short needle pine      1.0 Long needle pine      92.0 Other conifer Broadleaf deciduous      4.0 Broadleaf evergreen Palm frond Grass                      3.0		

Appendix A. Data used for FCCS fire behavior modeling- Healthy Fuelbed

**FUELBED INPUT REPORT**

Author:

Date: Feb 7, 2012

Fuelbed number: 24

File Name:

Data quality ranking:

Description: healthy sites,finalized

**GROUND FUELS - DUFF**

Input variable	Duff	Upper duff	Lower Duff
Percent Rotten	3.00 ( 0.00 / 20.00 )	N/A	N/A
Depth ( cm )	N/A	1.3 ( 0.5 / 3.6 )	0.3 ( 0.0 / 3.6 )
Percent Cover (%)	N/A	80.00 ( 40.00 / 90.00 )	80.00 ( 40.00 / 90.00 )
Derivation	N/A	Partially decomposed sphagnum or sedge	Fully decomposed sphagnum or sedge

**GROUND FUELS - SQUIRREL MIDDENS AND BASAL ACCUMULATIONS**

Input variable	Squirrel middens	Basal accumulations
Depth ( cm )		5.1 ( 3.8 / 10.2 )
Radius ( m )		0.3 ( 0.2 / 0.6 )
Density (#/ha)		N/A
Percent affected (%)	N/A	20.00 ( 0.00 / 75.00 )
Type	N/A	Bark slough

Appendix B. Key to species codes.

Code	Latin name	Common name
1FORB	unknown forb	
1GRAM	unknown graminoid	
1LSHB	unknown low shrub	
ABGR	<i>Abies grandis</i>	grand fir
ABGRS	<i>Abies grandis</i>	grand fir seedling
ACMI	<i>Achillea millefolium</i>	yarrow
ANMA	<i>Anaphalis margaritaea</i>	pearly everlasting
APAN	<i>Apocynum androsaemifolium</i>	dogbane
ARNE	<i>Arctostaphylos nevadensis</i>	pine mat manzanita
berberis	<i>Berberis sp.</i>	oregon grape
bracken	<i>Pteridium aquilinum</i>	bracken fern
CEVE	<i>Ceanothus velutinus</i>	Ceanothus
CHNA	<i>Chrysothamnus nauseosus</i>	rabbit brush
CHUM	<i>Chimaphila umbellata</i>	prince's pine
COCO	<i>Corylus cornuta</i>	hazel
COGR	<i>Collimia grandiflora</i>	phlox family
cornus	<i>Cornus sp.</i>	dogwood
EPAN	<i>Epilobium angustifolium</i>	epilobium
FRVI	<i>Fragaria virginiana</i>	strawberry
hazel	<i>Corylus cornuta</i>	hazel
HISP	<i>Hieracium sp</i>	hawkweed
HODI	<i>Holodiscus discolor</i>	oceanspray
HYRA	<i>Hypochaeris radicata</i>	hairy cat's ear
KEGA	<i>Kellogia galliodes</i>	Rubiaceae
LANE	<i>Lathyrus nevadensis</i>	peavine, vetch
LONE	<i>Lotus nevadensis</i>	pea family
LONU	<i>Lomatium nudicaule</i>	parsley
LUSP	<i>Lupine sp.</i>	lupin

ocean	<i>Holodiscus discolor</i>	ocean spray
OSCH	<i>Osmorhiza chilensis</i>	parsley family
PEGA	<i>Perideria gairdneri</i>	parsley family
PICO	<i>Pinus contorta</i>	lodgepole pine
PIPO	<i>Pinus ponderosa</i>	ponderosa pine
PIPOS	<i>Pinus ponderosa</i>	ponderosa pine seedling
prunus	<i>Prunus sp.</i>	cherry
PSME	<i>Psuedotsuga mensiizei</i>	doug fir
PSMES	<i>Psuedotsuga mensiizei</i>	doug fir seedling
PRSP	<i>Prunus sp</i>	cherry
PTAN	<i>Pterospora andromedea</i>	pine drops
PTAQ	<i>Pteridium aquilinum</i>	bracken fern
PUTR	<i>Pursia tridentata</i>	bitterbrush
PYCH	<i>Pyrola chlorantha</i>	green wintergreen
QUGA	<i>Quercus garryana</i>	oregon oak
rabbit	<i>Chrysothamnus nauseosus</i>	rabbit brush
rosa	<i>Rosa sp.</i>	rose
ROSP	<i>Rosa sp.</i>	rose
RUAC	<i>Rumex acetosella</i>	polygonaceae
RUUR	<i>Rubus ursinus</i>	blackberry
snowberry	<i>Symphoricarpos albus</i>	snowberry
SPDO	<i>Spirea douglassii</i>	spirea
spirea	<i>Spirea sp.</i>	spirea
SYAL	<i>Symphoricarpos albus</i>	snowberry
TRLA	<i>Trientalis latifolia</i>	western starflower
VASC	<i>Vaccinium scoparium</i>	huckleberry
VIAM	<i>Vicia americana</i>	
willow	<i>Salix sp.</i>	willow

Appendix C. Sum of percent cover in 6 1m<sup>2</sup> ground cover survey plots

Site	Disease	Bearing	Bare ground	Duff	Long Needles	Hardwood	Grass	Rotten Wood	Sound Wood	Bark	Moss	Rock	Lichen	Cones	Short Needles	Mat-forming vegetation
Cow-041	1	0	0	1	80	5	2	t	12	t	0	0	0	0	0	0
Cow-041	1	60	0	0	70	t	30	0	t	t	0	0	t	0	0	0
Cow-041	1	120	0	t	75	t	24	0	1	t	0	0	t	0	0	0
Cow-041	1	180	0	0	70	7	10	0	10	3	0	0	t	0	0	0
Cow-041	1	240	15	0	82	1	2	0	t	t	0	0	0	t	0	0
Cow-041	1	300	15	0	79	1	3	0	1	1	0	t	t	0	0	0
Cow-040	0	0	0	0	88	0	5	0	2	2	0	0	1	2	0	0
Cow-040	0	60	0	0	84	0	2	0	8	1	t	0	t	5	0	0
Cow-040	0	120	0	1	98	0	1	t	t	t	0	0	t	t	0	0
Cow-040	0	180	t	1	96	0	t	2	1	t	0	0	t	t	0	0
Cow-040	0	240	0	0	98	t	t	1	t	t	0	0	t	1	0	0
Cow-040	0	300	0	0	98	0	t	t	2	t	0	0	t	0	0	0
Mist-043	0	0	0	0	89	1	0	5	0	5	0	0	0	0	0	0
Mist-043	0	60	0	0	95	3	0	2	0	t	0	0	0	0	0	0
Mist-043	0	120	0	0	79	5	0	15	0	1	0	0	0	0	0	0
Mist-043	0	180	0	0	95	5	0	0	0	0	0	0	0	0	0	0
Mist-043	0	240	0	0	98	0	0	1	0	1	0	0	0	0	0	0
Mist-043	0	300	0	0	95	0	0	5	0	0	0	0	0	0	0	0
Mist-042	1	0	0	0	88	0	0	10	1	1	0	0	0	0	0	0
Mist-042	1	60	0	0	83	0	0	15	0	2	0	0	0	0	0	0
Mist-042	1	120	0	0	86	0	2	10	0	t	2	0	0	0	0	0
Mist-042	1	180	0	0	97	0	t	3	0	0	0	0	0	0	0	0
Mist-042	1	240	0	0	90	0	0	10	0	t	0	0	0	0	0	0
Mist-042	1	300	0	0	90	0	0	10	0	t	0	0	0	0	0	0
Wet-044	0	0	0	0	100	t	t	0	t	t	0	0	t	0	0	0
Wet-044	0	60	0	t	74	20	0	0	6	t	0	0	t	0	0	0
Wet-044	0	120	0	0	67	0	0	25	5	3	0	0	0	0	0	0
Wet-044	0	180	t	t	94	t	0	6	0	t	0	0	0	0	0	0
Wet-044	0	240	0	0	80	20	0	0	t	t	0	0	t	0	0	0
Wet-044	0	300	0	t	92	8	0	0	0	t	0	0	t	0	0	0
Wet-045	1	0	10	44	20	8	2	0	10	6	0	0	t	t	0	0
Wet-045	1	60	0	5	78	3	5	t	t	t	0	0	t	9	0	0
Wet-045	1	120	0	t	88	t	t	2	7	1	t	t	t	2	0	0
Wet-045	1	180	0	t	83	4	t	8	5	t	0	0	t	t	0	0

Site	Disease	Bearing	Bare ground	Duff	Long Needles	Hardwood	Grass	Rotten Wood	Sound Wood	Bark	Moss	Rock	Lichen	Cones	Short Needles	Mat-forming vegetation
Wet-045	1	240	t	t	74	5	5	0	15	1	0	0	0	0	0	0
Wet-045	1	300	25	0	20	21	20	0	8	t	6	t	t	t	0	0
Hill-051	1	60	0	5	5	10	5	5	1	0	0	0	0	0	69	0
Hill-051	1	120	1	10	5	20	0	1	1	0	0	0	0	0	62	0
Hill-051	1	180	0	54	10	10	1	0	5	0	0	0	0	0	20	0
Hill-051	1	240	0	0	1	10	0	0	84	5	0	0	0	0	0	0
Hill-051	1	300	0	5	10	10	0	0	50	20	0	0	0	0	5	0
Hill-052	0	0	0	0	89	t	10	t	1	t	0	0	0	0	0	0
Hill-052	0	60	0	0	94	5	1	t	t	t	0	0	0	0	0	0
Hill-052	0	120	2	0	93	5	0	t	t	0	0	0	0	0	0	0
Hill-052	0	180	0	0	99	0	0	1	0	0	0	0	0	0	0	0
Hill-052	0	240	0	0	95	0	0	0	5	0	0	0	0	0	0	0
Hill-052	0	300	0	0	96	t	t	t	3	1	0	0	0	0	0	0
Bert_056	0	0	0	0	99	0	1	0	0	0	0	0	0	0	0	0
Bert_056	0	60	0	0	98	0	1	1	0	0	0	0	0	0	0	0
Bert_056	0	120	0	0	98	0	1	1	0	0	0	0	0	0	0	0
Bert_056	0	180	0	0	98	0	1	1	0	0	0	0	0	0	0	0
Bert_056	0	240	0	0	98	0	1	1	0	0	0	0	0	0	0	0
Bert_056	0	300	0	0	95	0	0	0	5	0	0	0	0	0	0	0
Bert_055	1	0	0	0	90	0	10	0	0	0	0	0	0	0	0	0
Bert_055	1	60	0	10	75	0	10	5	0	0	0	0	0	0	0	0
Bert_055	1	120	t	45	40	5	5	t	5	t	0	0	0	0	0	0
Bert_055	1	180	1	53	40	0	1	5	0	0	0	0	0	0	0	0
Bert_055	1	240	0	10	75	0	t	10	0	5	0	0	0	0	0	0
Bert_055	1	300	0	0	83	t	15	0	2	0	0	0	0	0	0	0
Oak_050	1	0	0	0	5	5	90	0	t	0	0	0	0	0	0	0
Oak_050	1	60	2	0	25	t	57	0	15	1	0	0	0	0	0	0
Oak_050	1	120	0	0	5	0	93	0	2	0	0	0	0	0	0	0
Oak_050	1	180	0	0	10	1	68	0	10	1	10	0	0	0	0	0
Oak_050	1	240	0	0	3	5	77	0	12	3	0	0	0	0	0	0
Oak_050	1	300	0	0	20	15	50	0	15	0	0	0	0	0	0	0
Oak_049	0	0	0	0	90	1	t	2	7	0	0	0	0	0	0	0
Oak_049	0	60	0	0	92	3	1	1	3	0	0	0	0	0	0	0
Oak_049	0	120	0	0	89	3	1	5	2	0	0	0	0	0	0	0
Oak_049	0	180	0	0	94	3	0	T	3	0	0	0	0	0	0	0
Oak_049	0	240	0	0	73	11	1	0	15	0	0	0	0	0	0	0
Oak_049	0	300	3	0	86	t	1	0	10	0	0	0	0	0	0	0

Site	Disease	Bearing	Bare ground	Duff	Long Needles	Hardwood	Grass	Rotten Wood	Sound Wood	Bark	Moss	Rock	Lichen	Cones	Short Needles	Mat-forming vegetation
Sun_054	0	0	0	0	94	1	t	5	t	0	0	0	0	0	0	0
Sun_054	0	60	0	0	94	0	0	0	5	1	0	0	0	0	0	0
Sun_054	0	120	0	0	98	0	1	0	1	0	0	0	0	0	0	0
Sun_054	0	180	0	0	85	0	0	15	0	0	0	0	0	0	0	0
Sun_054	0	240	0	0	74	1	0	0	25	0	0	0	0	0	0	0
Sun_054	0	300	0	0	85	0	0	5	10	0	0	0	0	0	0	0
Sun_053	1	0	0	0	79	1	20	0	0	0	0	0	0	0	0	0
Sun_053	1	60	0	0	75	5	20	0	0	0	0	0	0	0	0	0
Sun_053	1	120	0	0	25	0	60	0	15	0	0	0	0	0	0	0
Sun_053	1	180	0	0	20	0	80	T	0	0	0	0	0	0	0	0
Sun_053	1	240	0	19	20	0	50	0	10	1	0	0	0	0	0	0
Sun_053	1	300	0	23	20	5	40	1	1	10	0	0	0	0	0	0
Jenn_057	1	0	0	0	90	10	0	0	0	0	0	0	0	0	0	0
Jenn_057	1	60	0	0	79	10	0	1	10	0	0	0	0	0	0	0
Jenn_057	1	120	0	0	80	0	5	15	0	0	0	0	0	0	0	0
Jenn_057	1	180	5	12	30	t	15	25	0	13	0	0	0	0	0	0
Jenn_057	1	240	0	0	65	t	30	0	5	0	0	0	0	0	0	0
Jenn_057	1	300	t	10	75	0	10	0	5	0	0	0	0	0	0	0
Jenn_058	0	0	0	0	99	1	t	0	0	0	0	0	0	0	0	0
Jenn_058	0	60	0	0	100	0	t	0	0	0	0	0	0	0	0	0
Jenn_058	0	120	0	0	99	0	0	0	1	0	0	0	0	0	0	0
Jenn_058	0	180	0	0	100	0	0	0	0	0	0	0	0	0	0	0
Jenn_058	0	240	0	0	95	5	0	0	0	0	0	0	0	0	0	0
Jenn_058	0	300	0	0	84	0	15	1	0	0	0	0	0	0	0	0
Anne_062	0	0	0	0	77	20	t	0	3	0	0	0	t	0	0	0
Anne_062	0	60	0	0	64	25	1	10	t	t	0	0	0	0	0	0
Anne_062	0	120	0	3	72	5	1	15	3	1	0	0	t	0	0	0
Anne_062	0	180	0	0	69	20	5	0	5	0	0	0	1	0	0	0
Anne_062	0	240	0	0	75	10	5	5	5	0	0	0	0	0	0	0
Anne_062	0	300	0	5	53	20	1	T	20	1	0	0	t	0	0	0
Anne_063	1	0	0	20	44	20	5	3	3	5	0	0	0	0	0	0
Anne_063	1	60	0	0	59	15	5	20	1	t	0	0	t	0	0	0
Anne_063	1	120	0	5	30	30	t	T	30	5	0	0	0	0	0	0
Anne_063	1	180	0	1	49	10	t	10	30	0	0	0	0	0	0	0
Anne_063	1	240	0	15	64	10	10	0	t	t	1	0	t	0	0	0
Anne_063	1	300	0	t	64	25	10	1	0	t	0	0	0	0	0	0

Site	Disease	Bearing	Bare ground	Duff	Long Needles	Hardwood	Grass	Rotten Wood	Sound Wood	Bark	Moss	Rock	Lichen	Cones	Short Needles	Mat-forming vegetation
Who_065	1	60	5	20	35	5	25	0	10	t	0	t	0	0	0	0
Who_065	1	120	0	5	40	10	35	0	10	t	0	0	0	0	0	0
Who_065	1	180	0	15	59	20	0	5	1	t	0	0	t	0	0	0
Who_065	1	240	0	5	73	15	1	5	1	0	0	0	0	0	0	0
Who_065	1	300	0	5	70	10	t	10	5	t	0	0	t	0	0	0
Who_064	0	0	0	5	71	1	t	0	20	3	0	0	t	0	0	0
Who_064	0	60	0	1	79	t	t	0	20	t	0	0	t	0	0	0
Who_064	0	120	0	1	77	1	t	0	20	1	0	0	0	0	0	0
Who_064	0	180	0	1	80	1	0	1	15	1	0	0	1	0	0	0
Who_064	0	240	0	0	40	20	35	0	5	0	0	0	t	0	0	0
Who_064	0	300	0	0	64	1	35	0	0	0	0	0	0	0	0	0
Grass_060	0	0	0	0	89	t	1	10	0	t	0	0	t	0	0	0
Grass_060	0	60	0	t	90	t	1	0	5	4	0	0	t	0	0	0
Grass_060	0	120	0	0	95	t	t	0	5	0	0	0	t	0	0	0
Grass_060	0	180	0	t	87	t	2	5	5	1	0	0	t	0	0	0
Grass_060	0	240	3	t	94	2	t	0	1	t	0	t	t	0	0	0
Grass_060	0	300	2	0	93	t	t	5	t	t	0	0	t	0	0	0
Grass_061	1	0	t	0	80	5	10	5	0	0	0	0	0	0	0	0
Grass_061	1	60	5	0	69	3	3	20	0	0	0	0	0	0	0	0
Grass_061	1	120	t	0	61	5	15	15	3	t	0	0	1	0	0	0
Grass_061	1	180	15	5	47	5	3	5	20	0	0	t	0	0	0	0
Grass_061	1	240	0	t	90	5	2	0	3	0	0	0	t	0	0	0
Grass_061	1	300	3	1	92	1	2	1	0	0	0	0	0	0	0	0
Next_067	1	0	0	1	59	40	0	t	t	0	0	0	0	0	0	0
Next_067	1	60	0	t	95	2	1	0	1	1	0	0	t	0	0	0
Next_067	1	120	10	0	85	5	0	0	t	t	0	t	0	0	0	0
Next_067	1	180	0	0	61	30	t	3	5	1	0	0	0	0	0	0
Next_067	1	240	0	t	71	15	0	10	3	1	0	0	0	0	0	0
Next_067	1	300	0	4	80	10	t	1	t	5	0	0	0	0	0	0
Next_068	0	0	0	t	94	5	t	1	t	t	0	0	0	0	0	0
Next_068	0	60	0	2	90	1	t	2	0	5	0	0	t	0	0	0
Next_068	0	120	0	2	94	2	t	2	t	t	0	0	0	0	0	0
Next_068	0	180	0	5	93	t	t	t	t	2	0	0	t	0	0	0
Next_068	0	240	0	t	60	30	t	t	10	t	0	0	0	0	0	0
Next_068	0	300	0	0	73	10	2	10	3	2	0	0	t	0	0	0

Site	Disease	Bearing	Bare ground	Duff	Long Needles	Hardwood	Grass	Rotten Wood	Sound Wood	Bark	Moss	Rock	Lichen	Cones	Short Needles	Mat-forming vegetation
Lake1_004	0	60	t	0	100	t	t	0	0	0	0	0	0	0	0	0
Lake1_004	0	120	0	0	98	0	1	1	0	0	0	0	0	0	0	0
Lake1_004	0	180	0	0	100	0	t	0	0	0	0	0	0	0	0	0
Lake1_004	0	240	0	0	95	t	5	t	0	0	0	0	0	0	0	0
Lake1_004	0	300	0	0	95	0	5	0	0	0	0	0	0	0	0	0
Lake1_009	1	0	0	0	84	0	5	1	5	5	0	0	0	0	0	0
Lake1_009	1	60	0	0	69	0	5	1	0	25	0	0	0	0	0	0
Lake1_009	1	120	0	0	44	0	1	5	20	30	0	0	0	0	0	0
Lake1_009	1	180	0	0	93	0	0	5	1	1	0	0	0	0	0	0
Lake1_009	1	240	0	0	98	0	t	1	1	t	0	0	0	0	0	0
Lake1_009	1	300	0	0	78	0	1	10	10	1	0	0	0	0	0	0
Air_035	1	0	1	5	93	0	0	0	1	0	0	0	0	0	0	0
Air_035	1	60	1	5	92	0	0	1	1	0	0	0	0	0	0	0
Air_035	1	120	0	5	93	0	0	1	1	0	0	0	0	0	0	0
Air_035	1	180	0	5	89	0	0	5	1	0	0	0	0	0	0	0
Air_035	1	240	1	5	87	0	0	5	1	1	0	0	0	0	0	0
Air_035	1	300	1	27	70	0	0	1	1	0	0	0	0	0	0	0
Air_033	0	0	0	9	90	0	0	0	1	0	0	0	0	0	0	0
Air_033	0	60	1	9	89	0	0	1	0	0	0	0	0	0	0	0
Air_033	0	120	0	1	98	0	0	1	0	0	0	0	0	0	0	0
Air_033	0	180	0	0	85	5	0	0	10	0	0	0	0	0	0	0
Air_033	0	240	0	0	90	5	0	0	5	0	0	0	0	0	0	0
Air_033	0	300	0	0	95	0	0	0	5	0	0	0	0	0	0	0
K2000_038	1	0	1	90	5	1	0	1	1	1	0	0	0	0	0	0
K2000_038	1	60	1	25	1	0	57	1	15	0	0	0	0	0	0	0
K2000_038	1	120	0	65	5	0	23	1	1	5	0	0	0	0	0	0
K2000_038	1	180	15	68	1	0	10	1	5	0	0	0	0	0	0	0
K2000_038	1	240	10	41	1	1	40	1	5	1	0	0	0	0	0	0
K2000_038	1	300	0	59	0	1	30	5	5	0	0	0	0	0	0	0
K2000_037	0	0	0	1	97	0	0	1	1	0	0	0	0	0	0	0
K2000_037	0	60	0	0	95	0	0	5	0	0	0	0	0	0	0	0
K2000_037	0	120	0	1	73	0	0	0	1	0	0	0	0	0	0	25
K2000_037	0	180	0	1	98	0	0	0	1	0	0	0	0	0	0	0
K2000_037	0	240	0	1	93	0	0	5	1	0	0	0	0	0	0	0
K2000_037	0	300	0	1	93	0	0	0	5	1	0	0	0	0	0	0

Appendix D. Sum of percent cover for 6 1m<sup>2</sup> herbaceous survey plots.

Site	Disease	1FORB	1GRAM	ACMI	ANMA	APAN	ARNE	CEVE	CHNA	CHUM	COCO	EPAN	FRVI	HISP	HODI	HYRA	KEGA
Air1_033	0	64	27	0	0	0	7	0	0	0	0	0	0	0	0	0	0
Air1_035	1	17	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anne_062	0	t	55	t	0	0	0	0	0	0	0	0	0	t	0	0	4
Anne_063	1	5	95	t	3	0	0	0	0	5	0	0	8	6	0	0	19
Bert_055	1	11	176	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bert_056	0	18	70	10	0	0	0	0	48	0	0	0	0	0	0	0	0
Cow_040	0	2	87	8	0	0	0	0	0	0	0	0	0	4	0	0	0
Cow_041	1	1	175	2	0	0	t	0	0	0	0	0	0	13	0	0	2
Grass_061	1	6	115	3	0	0	0	1	25	13	0	t	29	7	0	10	38
Grass_062	0	1	30	1	0	0	0	0	0	0	0	0	0	t	0	0	0
Hill_051	1	32	1	t	0	0	0	0	0	0	0	0	t	0	0	0	0
Hill_052	0	37	56	0	0	0	20	1	0	0	0	0	0	0	0	0	0
Jenn_057	1	t	65	5	0	0	0	5	0	0	0	0	0	0	0	0	0
Jenn_058	0	21	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K2000_037	0	18	37	0	0	0	0	0	0	25	0	0	0	0	0	0	0
K2000_038	1	65	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lake1_004	0	t	182	0	0	0	0	0	0	0	0	0	0	12	0	0	0
Lake1_009	1	t	85	1	0	0	0	0	0	0	0	0	0	1	0	0	0
Mist_042	1	2	19	1	0	0	5	0	0	0	0	0	0	2	0	0	0
Mist_043	0	1	7	3	0	0	15	0	0	0	5	0	0	t	0	0	0
Next_067	1	2	6	0	0	0	0	0	0	0	0	2	6	6	0	0	6
Next_068	0	1	9	8	0	4	0	0	0	0	0	0	0	2	0	0	34
Oak_049	0	57	t	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oak_050	1	30	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sun_053	1	6	145	15	0	0	0	0	0	0	0	0	0	0	0	0	0
Sun_054	0	6	10	1	0	0	0	0	0	0	0	0	25	0	0	0	0
Wet_044	0	t	2	1	0	0	0	0	0	0	0	0	0	4	0	0	3
Wet_045	1	0	81	9	0	0	0	0	0	0	0	1	t	26	0	0	t
Who_064	0	1	116	0	0	0	0	0	0	0	0	0	6	8	46	0	1
Who_065	1	0	95	0	0	5	0	0	0	0	5	0	0	1	0	0	0

Site	Disease	LONE	LONU	LUSP	OSCH	PEGA	PIPOS	PRSP	PSME	PSMES	PTAN	PTAQ	PUTR	PYCH	QUGA	ROSP	RUUR	RUAC	SPDO	SYAL	TRLA	VASC	VIAM
Air1_033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Air1_035	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anne_062	0	0	0	0	0	0	0	0	0	0	0	205	20	0	0	0	0	0	0	0	0	0	0
Anne_063	1	0	0	0	0	0	1	0	0	0	0	160	t	0	0	13	0	0	0	0	0	0	0
Bert_055	1	0	0	0	0	0	0	0	0	0	0	41	0	0	0	0	0	0	0	0	0	0	0
Bert_056	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0
Cow_040	0	0	0	3	0	0	0	0	0	t	0	0	0	0	0	0	0	0	0	0	0	0	0
Cow_041	1	6	0	1	0	0	t	0	0	0	0	63	0	0	0	0	0	0	0	0	0	0	0
Grass_061	1	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	55	0	0	1
Grass_062	0	10	23	0	0	1	t	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Hill_051	1	0	0	0	0	0	0	0	1	0	0	107	0	0	0	0	0	0	0	0	0	0	0
Hill_052	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jenn_057	1	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
Jenn_058	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0	0	0	0	0	0	0	0
K2000_037	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K2000_038	1	0	0	0	0	0	0	0	0	0	0	36	0	0	0	0	0	0	0	0	0	0	0
Lake1_004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lake1_009	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Mist_042	1	0	0	9	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Mist_043	0	0	0	0	0	0	0	0	0	0	0	158	0	0	0	0	0	0	0	0	0	0	0
Next_067	1	0	0	0	0	0	0	0	0	0	0	65	0	0	0	2	0	0	0	0	0	100	0
Next_068	0	0	0	2	0	0	6	0	0	0	0	0	0	0	0	0	0	0	71	32	0	0	0
Oak_049	0	0	0	0	0	0	0	0	0	1	0	7	0	0	2	0	0	0	0	0	0	0	0
Oak_050	1	0	0	0	0	0	0	5	0	4	0	115	0	0	0	0	0	0	0	4	0	0	0
Sun_053	1	0	0	t	0	0	0	0	0	0	0	90	0	0	0	0	0	0	0	5	0	0	0
Sun_054	0	0	0	t	0	0	0	0	0	0	0	45	0	0	0	0	0	0	0	5	0	0	0
Wet_044	0	1	0	0	0	0	0	0	0	0	0	95	0	0	0	0	0	0	0	0	0	0	0
Wet_045	1	20	t	6	0	0	0	0	0	0	0	45	0	0	0	0	0	3	0	0	0	0	1
Who_064	0	0	0	t	1	0	0	0	0	17	5	0	0	0	0	1	1	0	0	3	17	0	0
Who_065	1	0	0	0	0	0	0	0	0	6	0	85	0	5	0	1	0	0	0	32	12	0	0

Appendix E. Ladder fuel hazard ratings for four quadrants of each site.

Site	Disease	Obs 1	Obs 2	Obs 3	Obs 4
Air1_033	0	A	A	A	B
Air1_035	1	A	A	A	C
Anne_062	0	A	B	A	D
Anne_063	1	E	E	E	B
Bert_055	1	E	E	E	E
Bert_056	0	B	D	D	D
Cow_040	0	B	D	D	A
Cow_041	1	B	B	B	B
Grass_060	0	C	C	C	C
Grass_061	1	A	E	E	B
Hill_051	1	C	A	C	A
Hill_052	0	D	D	B	D
Jenn_057	1	A	B	B	B
Jenn_058	0	D	D	D	A
K2000_037	0	D	D	D	B
K2000_038	1	E	E	E	E
Lake1_004	0	D	D	D	B
Lake1_009	1	C	C	C	C
Mist_042	1	A	B	B	B
Mist_043	0	C	B	A	B
Next_067	1	D	E	D	D
Next_068	0	D	B	D	D
Oak_049	0	A	C	A	C
Oak_050	1	A	C	D	C
Sun_053	1	B	B	D	B
Sun_054	0	B	B	D	D
Wet_044	0	B	D	B	D
Wet_045	1	B	D	E	E
Who_064	0	A	B	C	B
Who_065	1	A	A	D	A

Class A- High risk, clumped and continuous fuels

Class B- Moderate risk, clumped fuels

Class C- Moderate risk, continuous fuels

Class D- Low risk, fuels not clumped or continuous

Class E- No risk, not forested

Appendix F. Average of 5 measurements of litter depth (mm) along three transects

Site	Disease	0 deg	120 deg	240 deg
Air-033	0	11.4	16.6	80.8
Air-035	1	18.4	26	15.2
Anne-062	0	37	29.4	28.8
Anne-063	1	23.6	161.2	45.6
Bert-055	1	15.2	25.8	19.6
Bert-056	0	44.4	44.4	50.4
Cow-040	0	13.4	19.4	16.8
Cow-041	1	11	15.4	23.2
Grass-060	0	16	22	30.4
Grass-061	1	42	37	35.6
Hill-051	1	86.2	25	112
Hill-052	0	24.2	24.8	63.2
Jenn-057	1	53.4	26	35
Jenn-058	0	31.4	46.6	43.6
K2000-037	0	36.4	41.8	26
K2000-038	1	1.8	-2.4	-6
Lake1-004	0	60.2	16.4	30.6
Lake1-009	1	19	14	14.2
Mist-042	1	15.6	25.6	18.8
Mist-043	0	17.6	41.4	17.6
Next-067	1	34.2	19.2	21.2
Next-068	0	15	38.4	18
Oak-049	0	39.6	31.8	31.8
Oak-050	1	16.2	38.6	29
Sun-053	1	23.4	51.6	12.4
Sun-054	0	32.6	57.8	57.4
Wet-044	0	22	36.6	20.6
Wet-045	1	19	14	12.6
Who-064	0	16.2	15.2	56.8
Who-065	1	49	78.6	16.6

Appendix G. Dry weight of litter in a 900cm<sup>2</sup> sample.

Site	Bearing	Disease	O-horizon dry weight (g)
Air_033	0	0	10
Air_033	120	0	37
Air_033	240	0	36
Air_035	0	1	16
Air_035	120	1	29
Air_035	240	1	20
Anne_062	0	0	40
Anne_062	120	0	36
Anne_062	240	0	31
Anne_063	0	1	17
Anne_063	120	1	77
Anne_063	240	1	13
Bert_055	0	0	26
Bert_055	120	1	13
Bert_055	240	1	26
Bert_056	0	0	10
Bert_056	120	0	22
Bert_056	240	0	21
Cow_040	0	0	34
Cow_040	120	0	36
Cow_040	240	0	41
Cow_041	0	1	19
Cow_041	120	1	37
Cow_041	240	1	23
Grass_060	0	0	26
Grass_060	120	0	41
Grass_060	240	0	21
Grass_061	0	1	30
Grass_061	120	1	23
Grass_061	240	1	17

Site	Bearing	Disease	O-horizon dry weight (g)
Hill_051	0	1	75
Hill_051	120	1	12
Hill_051	240	1	19
Hill_052	0	0	22
Hill_052	120	0	44
Hill_052	240	0	17
Jenn_057	0	1	23
Jenn_057	120	1	14
Jenn_057	240	1	12
Jenn_058	0	0	36
Jenn_058	120	0	44
Jenn_058	240	0	47
K2000_037	0	0	66
K2000_037	120	0	39
K2000_037	240	0	41
K2000_038	0	1	1
K2000_038	120	1	6
K2000_038	240	1	1
Lake1_004	0	0	30
Lake1_004	120	0	15
Lake1_004	240	0	27
Lake1_009	0	1	11
Lake1_009	120	1	3
Lake1_009	240	1	8
Mist_042	0	1	19
Mist_042	120	1	38
Mist_042	240	1	30
Mist_043	0	0	58
Mist_043	120	0	58
Mist_043	240	0	35

Site	Bearing	Disease	O-horizon dry weight (g)
Next_067	0	1	14
Next_067	120	1	16
Next_067	240	1	30
Next_068	0	0	37
Next_068	120	0	27
Next_068	240	0	15
Oak_049	0	0	31
Oak_049	120	0	24
Oak_049	240	0	27
Oak_050	0	1	28
Oak_050	120	1	14
Oak_050	240	1	10
Sun_053	0	1	9
Sun_053	120	1	18
Sun_053	240	1	15
Sun_054	0	0	33
Sun_054	120	0	20
Sun_054	240	0	39
Wet_044	0	0	63
Wet_044	120	0	75
Wet_044	240	0	51
Wet_045	0	1	0
Wet_045	120	1	17
Wet_045	240	1	39
Who_064	0	0	25
Who_064	120	0	11
Who_064	240	0	13
Who_065	0	1	25
Who_065	120	1	23
Who_065	240	1	22

Appendix H. Height and canopy base height (ft) of several representative trees.

Site	Disease	O1T	O2T	O3T	O1B	O2B	O3B	M1T	M2T	M3T	M1B	M2B	M3B
Air_033	0	116	75	75	30	30	8	39	60	35.25	24.75	18.75	22.5
Air_035	1	60	66	73	15	15	20	36.75	28.5	24.75	12.75	12	18
Anne_062	0	84	90	71	28	37	23	63.75	66	69	33.75	25.5	26.25
Anne_063	1	30	25	30	15	12	0	34	26	44	20	15	14
Bert_055	1	92	na	na	30	na	na	22	52	34	3	20	8
Bert_056	0	94	98	87	34	38	38	na	na	na	na	na	na
Cow_040	0	111	113	90	50	61	45	36	22	36	20	15	30
Cow_041	1	71	73	95	30	31	51	25	28	na	12	15	na
Grass_060	0	90	94	90	35	35	56	22	31	36	16	17	18
Grass_061	1	105	97	71	51	35	62	na	na	na	na	na	na
Hill_051	1	130	60	na	94	30	na	48	50	28	15	18	15
Hill_052	0	130	135	140	60	50	58	54	35	45	16	19	18
Jenn_057	1	87	55	63	24	26	23	55	40	40	23	28	32
Jenn_058	0	120	109	105	34	38	40	28	na	na	12	na	na
K2000_037	0	60	65	88	33	33	42	66	39	58	35	22	37
K2000_038	1	48	na	na	14	na	na	33	25	28	13	12	0
Lake1_004	0	105	93	107.25	48	30	36	42	38	40	5	10	8
Lake1_009	1	72.75	87.75	115.5	41.25	33.75	52.5	58	50	22	12	18	6
Mist_042	1	71	92	81	53	44	44	43	62	58	30	41	26
Mist_043	0	90	75	77	47	26	34	na	na	na	na	na	na
Next_067	1	99	45	77	53	10	50	45	38	48	12	3	4
Next_068	0	75	102	120	30	42	51	54	38	32	35	0	5
Oak_049	0	90	90	92	32	30	5	26	30	43	3	19	27
Oak_050	1	125	105	78	40	10	33	15	17	19	6	3	0
Sun_053	1	83	98	na	28	50	na	50	45	38	25	30	25
Sun_054	0	102	75	84	50	45	44	na	na	na	na	na	na
Wet_044	0	84	81	75	30	25	40	40	63	na	23	28	na
Wet_045	1	103	99	na	33	38	na	28	60	32	0	20	0
Who_064	0	96	128	70	34	12	36	62	na	na	45	na	na
Who_065	1	102	93	82	47	65	7	na	na	na	na	na	na

O- overstory tree, M- midstory tree; 1,2,3- sample tree identification; T-top height to tree, B-bottom height of tree.

Appendix I. Average of percent cover of shrubs estimated in four quadrants of a 20 ft. radius circle.

Site	Disease	putr	psme	pipa	pico	abgr	bracken	snowberry	ocean	rosa	willow	ceve	spirea	hazel	rabbit	berberis	cornus	quga	prunus
Air_033	0	1.25	0.25	3.75	0	0.25	0	0	0	0	0	22.8	0	0	0	0	0	0	0
Air_035	1	30	0	1.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anne_062	0	3	0	2.5	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0
Anne_063	1	0	0	13.8	0	22.5	8.75	0	0	0.5	0	6.25	0	0	0	0	0	0	0
Bert_055	1	0	0	7.5	0	0	5	0	0	0	0	7.5	0	0	0	0	0	0	0
Bert_056	0	0	0	0	0	0	9.25	0	0	0	0	4	0	0	9	0	0	0	0
Cow_040	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0
Cow_041	1	1.75	0	0.75	0	0.25	0	t	0	0.25	0	0	0	0	0.5	0	0	0	0
Grass_060	0	0.5	0	0	0	0	0	t	0	0	0	0	0	0	0	0	0	0	0
Grass_061	1	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hill_051	1	0	1.25	0.25	0	1.25	17.5	0.25	0	0	0	0	0	2	0	0	0	0	0
Hill_052	0	0	1.5	1.25	0	0	6.5	0	0	0	0	0	0	0	0	0	0	0	0.25
Jenn_057	1	0	7.75	7.75	0	6.25	4	0.5	0	0	0	6.25	0	0	0.25	0	0	0	0
Jenn_058	0	0	0	0	0	0	10	0	0	0	0	1.25	0	0	0	0	0	0	0
K2000_037	0	0	0	0	0	0.25	0	0	0	0	0	0.75	0	0	0	0	0	0	0
K2000_038	1	0.25	1.5	2	0	0.5	0	0	0	0	0	7.5	0	0	0	0	0	0	0
Lake1_004	0	12.5	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.25	0	0	0
Lake1_009	1	6.25	0	0.5	0	0	0	0.25	0	0	0	0	0	0	0.25	0	0	0	0
Mist_042	1	0	0.25	1.5	0	0	0	t	0	0.25	0	0	0	0	0	0	0	0	0
Mist_043	0	0	0	0	0	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0
Next_067	1	0	0	0	0.5	0	10	0	0	t	6.25	0.75	2.5	0	0	0	0	0	0
Next_068	0	1.25	0.25	0	1.5	0	1.25	0	0	0	1.25	1.5	17.5	0	0	0	0	0	0
Oak_049	0	0	0.5	38.8	0	0.25	2	0	0	0	0	0	0	1.75	0	0	0	0.25	0
Oak_050	1	0	3.25	0.5	0	0.25	4.5	0	0	0	0	1.25	0	0.25	0	0	0	0	0
Sun_053	1	0.25	0	1.5	0	1.5	18.8	0	0	0	0	0	0	0	0.25	0	0	0	0
Sun_054	0	0	0	0	0	1.25	9	0	0	0	0	0	0	0	0	4	1.25	0	0
Wet_044	0	23.8	0	0	0	0	0	t	0	0	0	3	0	0	0	t	0	0	0
Wet_045	1	2.75	0	3	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
Who_064	0	0	10	0	0	0.25	0.5	2.75	13.8	0	0	0	0	0	0	0	0	0	0
Who_065	1	0	5.25	0	0	0	11.3	0.25	0	t	0	0	0	7.5	0	0	0	0	0

Appendix J. Occurrence of dead woody fuels in three time-lag classes.

Site	Disease	Bearing	Slope	1hr	10hr	100hr
Air1-033	0	0	5	1	3	0
Air1-033	0	60	5	4	0	1
Air1-033	0	120	5	1	0	0
Air1-033	0	180	5	4	2	0
Air1-033	0	240	5	4	4	1
Air1-033	0	300	5	2	0	0
Air1-035	1	0	5	1	0	0
Air1-035	1	60	5	0	0	0
Air1-035	1	120	5	6	2	1
Air1-035	1	180	5	3	0	2
Air1-035	1	240	5	5	1	0
Air1-035	1	300	5	7	0	0
Anne-062	0	0	5	0	2	1
Anne-062	0	60	5	1	2	1
Anne-062	0	120	5	1	1	2
Anne-062	0	180	5	0	0	0
Anne-062	0	240	5	0	1	2
Anne-062	0	300	5	2	5	1
Anne-063	1	0	5	10	1	1
Anne-063	1	60	5	7	2	3
Anne-063	1	120	5	8	2	0
Anne-063	1	180	5	6	0	2
Anne-063	1	240	5	6	0	0
Anne-063	1	300	5	0	0	0
Bert-055	1	0	5	0	0	0
Bert-055	1	60	5	7	5	1
Bert-055	1	120	5	0	0	1
Bert-055	1	180	5	0	3	3
Bert-055	1	240	5	0	10	1
Bert-055	1	300	5	0	0	2
Bert-056	0	0	5	2	2	0
Bert-056	0	60	5	25	8	0
Bert-056	0	120	5	8	4	0
Bert-056	0	180	5	5	1	0
Bert-056	0	240	5	12	5	0
Bert-056	0	300	5	37	6	1

Site	Disease	Bearing	Slope	1hr	10hr	100hr
Cow-040	0	0	5	0	11	1
Cow-040	0	60	5	1	3	2
Cow-040	0	120	5	0	2	0
Cow-040	0	180	5	0	4	0
Cow-040	0	240	5	1	6	0
Cow-040	0	300	5	0	2	0
Cow-041	1	0	5	2	1	1
Cow-041	1	60	5	2	1	0
Cow-041	1	120	5	3	1	1
Cow-041	1	180	5	0	3	2
Cow-041	1	240	5	2	2	0
Cow-041	1	300	5	0	2	1
Grass-060	0	0	5	2	1	5
Grass-060	0	60	5	0	1	0
Grass-060	0	120	5	1	2	0
Grass-060	0	180	5	0	2	1
Grass-060	0	240	5	0	0	1
Grass-060	0	300	5	1	1	3
Grass-061	1	0	5	0	0	1
Grass-061	1	60	5	0	0	2
Grass-061	1	120	5	1	2	3
Grass-061	1	180	5	0	2	1
Grass-061	1	240	5	1	0	1
Grass-061	1	300	5	0	2	0
Hill-051	1	0	5	110	30	5
Hill-051	1	60	5	4	16	1
Hill-051	1	120	5	2	12	0
Hill-051	1	180	5	4	3	2
Hill-051	1	240	5	37	13	1
Hill-051	1	300	5	100	20	30
Hill-052	0	0	5	0	7	0
Hill-052	0	60	5	0	1	1
Hill-052	0	120	5	0	3	0
Hill-052	0	180	5	1	5	0
Hill-052	0	240	5	0	5	0
Hill-052	0	300	5	1	5	1

Site	Disease	Bearing	Slope	1hr	10hr	100hr
Jenn-057	1	0	5	3	2	4
Jenn-057	1	60	5	1	10	4
Jenn-057	1	120	5	1	18	5
Jenn-057	1	180	5	3	13	11
Jenn-057	1	240	5	2	5	4
Jenn-057	1	300	5	5	1	2
Jenn-058	0	0	5	0	1	0
Jenn-058	0	60	5	0	1	2
Jenn-058	0	120	5	0	0	0
Jenn-058	0	180	5	0	1	0
Jenn-058	0	240	5	0	2	0
Jenn-058	0	300	5	0	2	3
K2000-037	0	0	5	2	4	1
K2000-037	0	60	5	1	3	2
K2000-037	0	120	5	2	1	1
K2000-037	0	180	5	0	2	1
K2000-037	0	240	5	1	3	2
K2000-037	0	300	5	1	3	2
K2000-038	1	0	5	0	7	3
K2000-038	1	60	5	1	9	3
K2000-038	1	120	5	0	1	5
K2000-038	1	180	5	0	2	3
K2000-038	1	240	5	2	5	3
K2000-038	1	300	5	1	12	3
Lake1-004	0	340	5	6	4	0
Lake1-004	0	20	5	0	1	0
Lake1-004	0	80	5	1	0	0
Lake1-004	0	140	5	0	0	0
Lake1-004	0	200	5	0	1	0
Lake1-004	0	260	5	0	1	0
Lake1-009	1	0	5	11	4	2
Lake1-009	1	60	5	4	3	2
Lake1-009	1	120	5	3	3	2
Lake1-009	1	180	5	0	3	0
Lake1-009	1	240	5	3	2	0
Lake1-009	1	300	5	0	3	1

Site	Disease	Bearing	Slope	1hr	10hr	100hr
Mist-042	1	0	5	1	2	2
Mist-042	1	60	5	0	1	0
Mist-042	1	120	5	0	5	4
Mist-042	1	180	5	2	3	1
Mist-042	1	240	5	0	0	1
Mist-042	1	300	5	0	1	4
Mist-043	0	0	5	0	3	1
Mist-043	0	60	5	1	8	1
Mist-043	0	120	5	2	3	1
Mist-043	0	180	5	2	9	0
Mist-043	0	240	5	2	1	0
Mist-043	0	300	5	0	3	1
Next-067	1	0	5	1	0	1
Next-067	1	60	5	0	0	0
Next-067	1	120	5	1	1	0
Next-067	1	180	5	0	1	0
Next-067	1	240	5	6	4	2
Next-067	1	300	5	3	8	0
Next-068	0	0	5	0	0	0
Next-068	0	60	5	1	0	0
Next-068	0	120	5	2	0	1
Next-068	0	180	5	2	3	0
Next-068	0	240	5	0	1	0
Next-068	0	300	5	1	2	1
Oak-049	0	0	5	0	3	1
Oak-049	0	60	5	7	4	0
Oak-049	0	120	5	1	2	0
Oak-049	0	180	5	3	0	0
Oak-049	0	240	5	1	2	0
Oak-049	0	300	5	6	2	0
Oak-050	1	0	5	9	6	0
Oak-050	1	60	5	4	3	0
Oak-050	1	120	5	1	3	0
Oak-050	1	180	5	2	1	0
Oak-050	1	240	5	4	4	0
Oak-050	1	300	5	9	3	2

Site	Disease	Bearing	Slope	1hr	10hr	100hr
Sun-053	1	0	5	0	2	3
Sun-053	1	60	5	0	2	1
Sun-053	1	120	5	1	11	0
Sun-053	1	180	5	0	5	1
Sun-053	1	240	5	1	3	1
Sun-053	1	300	5	3	5	2
Sun-054	0	0	5	1	8	0
Sun-054	0	60	5	0	3	0
Sun-054	0	120	5	3	9	3
Sun-054	0	180	5	0	4	1
Sun-054	0	240	5	1	2	0
Sun-054	0	300	5	4	3	1
Wet-044	0	0	5	3	12	0
Wet-044	0	60	5	5	19	1
Wet-044	0	120	5	3	15	3
Wet-044	0	180	5	0	0	0
Wet-044	0	240	5	6	0	0
Wet-044	0	300	5	1	0	0
Wet-045	1	0	5	1	10	3
Wet-045	1	60	5	3	3	1
Wet-045	1	120	5	0	3	3
Wet-045	1	180	5	0	3	1
Wet-045	1	240	5	0	4	2
Wet-045	1	300	5	0	0	0
Who-064	0	0	5	7	2	0
Who-064	0	60	5	10	5	1
Who-064	0	120	5	27	2	1
Who-064	0	180	5	20	5	2
Who-064	0	240	5	5	8	1
Who-064	0	300	5	28	1	0
Who-065	1	0	5	24	12	1
Who-065	1	60	5	12	3	2
Who-065	1	120	5	12	3	3
Who-065	1	180	5	3	5	1
Who-065	1	240	5	9	1	2
Who-065	1	300	5	17	0	0

Appendix K. Occurrence of 1000hr fuels.

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Air1-033	0	0	nr	nr	nr	nr	5
Air1-033	0	60	4	q	0	0	5
Air1-033	0	60	4	q	0	0	5
Air1-033	0	60	4	q	0	0	5
Air1-033	0	120	4	q	0	0	5
Air1-033	0	180	8	q	0	1	5
Air1-033	0	240	14	q	0	q	5
Air1-033	0	300	nr	nr	nr	nr	5
Air1-035	1	0	4	q	0	0	5
Air1-035	1	0	6	q	1	q	5
Air1-035	1	60	6	1	0	0	5
Air1-035	1	120	18	q	0	q	5
Air1-035	1	120	4	q	1	0	5
Air1-035	1	180	11	1	0	0	5
Air1-035	1	180	4	q	0	0	5
Air1-035	1	240	4	q	0	0	5
Air1-035	1	240	16	1	0	0	5
Air1-035	1	240	5	q	0	q	5
Air1-035	1	300	nr	nr	nr	nr	5
Anne-062	0	0	nr	nr	nr	nr	5
Anne-062	0	60	18	0	0	0	5
Anne-062	0	60	4	0	0	0	5
Anne-062	0	120	17	0	0	0	5
Anne-062	0	120	6	0	0	1	5
Anne-062	0	120	4	0	0	0	5
Anne-062	0	180	note	note	note	note	5
Anne-062	0	180	5	0	0	1	5
Anne-062	0	240	4	0	0	0	5
Anne-062	0	240	6	1	1	0	5
Anne-062	0	300	3.5	0	0	0	5
Anne-062	0	300	4	0	0	1	5
Anne-062	0	300	5	0	1	1	5
Anne-062	0	300	15	0	0	0	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Anne-063	1	0	5	0	0	0	5
Anne-063	1	60	5	0	0	0	5
Anne-063	1	60	9	1	1	0	5
Anne-063	1	120	7	0	0	0	5
Anne-063	1	120	8	1	1	0	5
Anne-063	1	120	14	1	1	0	5
Anne-063	1	180	6	0	1	0	5
Anne-063	1	180	5	0	0	1	5
Anne-063	1	180	9	1	1	0	5
Anne-063	1	180	5	0	0	0	5
Anne-063	1	240	4	0	1	1	5
Anne-063	1	300	6	0	1	0	5
Bert-055	1	0	15.7	1	1	0	5
Bert-055	1	0	8.6	1	1	0	5
Bert-055	1	60	4.8	1	1	0	5
Bert-055	1	60	8.8	1	1	0	5
Bert-055	1	60	10.5	1	1	0	5
Bert-055	1	60	5.8	1	0	0	5
Bert-055	1	60	11.5	1	1	0	5
Bert-055	1	120	6	1	1	0	5
Bert-055	1	120	12	1	1	0	5
Bert-055	1	180	5	1	1	0	5
Bert-055	1	240	7.5	1	1	0	5
Bert-055	1	300	12.3	1	1	0	5
Bert-055	1	300	8.3	1	1	0	5
Bert-056	0	0	nr	nr	nr	nr	5
Bert-056	0	60	nr	nr	nr	nr	5
Bert-056	0	120	nr	nr	nr	nr	5
Bert-056	0	180	nr	nr	nr	nr	5
Bert-056	0	240	nr	nr	nr	nr	5
Bert-056	0	300	nr	nr	nr	nr	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Cow-040	0	0	3	0	0	0	5
Cow-040	0	0	3	0	0	0	5
Cow-040	0	0	3	0	0	0	5
Cow-040	0	60	4.8	0	1	0	5
Cow-040	0	120	3.3	0	0	0	5
Cow-040	0	120	6	0	1	0	5
Cow-040	0	120	3.5	0	1	0	5
Cow-040	0	180	3	0	0	0	5
Cow-040	0	240	3	0	1	0	5
Cow-040	0	300	11	0	1	0	5
Cow-041	1	0	4	0	0	0	5
Cow-041	1	60	nr	nr	nr	nr	5
Cow-041	1	120	6	1	1	0	5
Cow-041	1	120	4	0	0	0	5
Cow-041	1	180	7	q	1	0	5
Cow-041	1	180	10	1	1	0	5
Cow-041	1	180	12	q	0	0	5
Cow-041	1	180	5	q	1	0	5
Cow-041	1	180	13	1	1	0	5
Cow-041	1	180	4	q	1	0	5
Cow-041	1	240	4	q	0	0	5
Cow-041	1	240	6	q	1	0	5
Cow-041	1	300	nr	nr	nr	nr	5
Grass-060	0	0	nr	nr	nr	nr	5
Grass-060	0	60	12	0	0	0	5
Grass-060	0	60	5	0	0	0	5
Grass-060	0	60	4	0	0	0	5
Grass-060	0	120	7	0	0	1	5
Grass-060	0	120	3	0	0	1	5
Grass-060	0	120	3.5	0	0	0	5
Grass-060	0	120	4	0	0	0	5
Grass-060	0	180	3.5	0	0	0	5
Grass-060	0	180	3.5	0	0	0	5
Grass-060	0	180	4	0	0	1	5
Grass-060	0	180	4	0	0	1	5
Grass-060	0	180	4	0	0	1	5
Grass-060	0	240	3.5	0	0	1	5
Grass-060	0	300	3.5	0	0	0	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Grass-061	1	0	5	1	1	0	5
Grass-061	1	0	10	1	1	0	5
Grass-061	1	0	5	0	0	1	5
Grass-061	1	60	3.5	0	0	0	5
Grass-061	1	60	3	0	1	0	5
Grass-061	1	60	5	0	0	1	5
Grass-061	1	60	4	0	0	0	5
Grass-061	1	120	8	1	1	0	5
Grass-061	1	120	6	1	1	0	5
Grass-061	1	120	4	1	1	0	5
Grass-061	1	120	4	0	0	0	5
Grass-061	1	120	5	0	1	0	5
Grass-061	1	180	7	0	1	1	5
Grass-061	1	180	4	0	1	1	5
Grass-061	1	180	5	1	1	0	5
Grass-061	1	180	8	1	1	0	5
Grass-061	1	180	6	1	1	0	5
Grass-061	1	180	11	1	1	0	5
Grass-061	1	180	4	0	1	0	5
Grass-061	1	180	9	1	1	0	5
Grass-061	1	180	7	1	0	0	5
Grass-061	1	180	4	0	1	0	5
Grass-061	1	240	8	1	1	0	5
Grass-061	1	240	3.5	1	1	0	5
Grass-061	1	240	6	1	1	0	5
Grass-061	1	240	16	1	1	0	5
Grass-061	1	240	4	0	1	0	5
Grass-061	1	240	9	0	0	0	5
Grass-061	1	300	5	1	1	0	5
Grass-061	1	300	11	1	1	0	5
Grass-061	1	300	12	1	0	0	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Hill-051	1	0	6.5	1	1	0	5
Hill-051	1	0	17	1	1	0	5
Hill-051	1	0	3.5	1	1	0	5
Hill-051	1	60	3.5	0	1	0	5
Hill-051	1	120	5.5	1	1	0	5
Hill-051	1	120	9	1	1	0	5
Hill-051	1	180	10	1	1	0	5
Hill-051	1	180	13	1	1	0	5
Hill-051	1	180	8	0	1	0	5
Hill-051	1	240	15	0	1	0	5
Hill-051	1	240	15.5	1	1	0	5
Hill-051	1	300	18.5	1	1	0	5
Hill-052	0	0	5.5	0	1	0	5
Hill-052	0	0	3	1	1	0	5
Hill-052	0	0	5	1	0	0	5
Hill-052	0	60	4.3	0	0	0	5
Hill-052	0	120	nr	nr	nr	nr	5
Hill-052	0	180	3.5	1	1	0	5
Hill-052	0	240	nr	nr	nr	nr	5
Hill-052	0	300	5.7	0	0	0	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Jenn-057	1	0	4.5	1	1	0	5
Jenn-057	1	0	6.4	1	1	0	5
Jenn-057	1	60	4.3	1	0	0	5
Jenn-057	1	60	5.4	1	1	0	5
Jenn-057	1	120	4.5	1	1	0	5
Jenn-057	1	120	3	1	0	0	5
Jenn-057	1	120	4.8	1	1	0	5
Jenn-057	1	120	3.1	0	1	0	5
Jenn-057	1	180	3.7	1	1	0	5
Jenn-057	1	180	3.5	1	1	0	5
Jenn-057	1	180	5.1	1	0	0	5
Jenn-057	1	180	5.4	1	1	0	5
Jenn-057	1	180	3.6	1	0	0	5
Jenn-057	1	180	6.4	1	1	0	5
Jenn-057	1	240	8	0	0	0	5
Jenn-057	1	240	8.5	0	1	0	5
Jenn-057	1	240	3.1	1	1	0	5
Jenn-057	1	240	4.6	1	1	0	5
Jenn-057	1	300	4	1	1	0	5
Jenn-057	1	300	3.7	0	1	0	5
Jenn-057	1	300	3.2	1	1	0	5
Jenn-058	0	0	3.5	0	0	0	5
Jenn-058	0	60	nr	nr	nr	nr	5
Jenn-058	0	120	nr	nr	nr	nr	5
Jenn-058	0	180	3.5	0	0	0	5
Jenn-058	0	240	nr	nr	nr	nr	5
Jenn-058	0	300	nr	nr	nr	nr	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
K2000-037	0	0	4.5	0	0	1	5
K2000-037	0	0	3.5	1	0	0	5
K2000-037	0	60	4	0	0	1	5
K2000-037	0	60	6	0	0	1	5
K2000-037	0	60	3.5	0	0	1	5
K2000-037	0	60	4	0	0	1	5
K2000-037	0	120	4.5	0	0	1	5
K2000-037	0	120	3.5	0	0	1	5
K2000-037	0	120	18	0	1	1	5
K2000-037	0	120	3.5	0	0	1	5
K2000-037	0	180	5	0	0	1	5
K2000-037	0	180	4	0	0	1	5
K2000-037	0	180	6	0	0	1	5
K2000-037	0	180	4	0	1	1	5
K2000-037	0	240	5	0	1	1	5
K2000-037	0	300	5	0	0	1	5
K2000-037	0	300	3.5	0	0	1	5
K2000-037	0	300	5	1	1	0	5
K2000-037	0	300	4	0	1	0	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
K2000-038	1	0	4	0	1	1	5
K2000-038	1	60	8	0	0	1	5
K2000-038	1	60	18	1	1	0	5
K2000-038	1	60	4	1	0	0	5
K2000-038	1	60	6.5	1	1	0	5
K2000-038	1	60	6	1	1	0	5
K2000-038	1	60	6.5	1	1	0	5
K2000-038	1	120	3.5	0	1	0	5
K2000-038	1	120	7	1	1	0	5
K2000-038	1	120	6	0	1	1	5
K2000-038	1	120	5	0	0	1	5
K2000-038	1	120	5	1	0	0	5
K2000-038	1	120	5	0	0	1	5
K2000-038	1	120	8	1	1	0	5
K2000-038	1	120	5	1	1	0	5
K2000-038	1	120	8	1	1	0	5
K2000-038	1	180	6	1	1	0	5
K2000-038	1	180	7	1	1	0	5
K2000-038	1	180	6	1	1	0	5
K2000-038	1	180	4	1	0	0	5
K2000-038	1	180	3.5	1	0	0	5
K2000-038	1	180	6	1	0	0	5
K2000-038	1	180	5	1	0	0	5
K2000-038	1	180	5	1	0	0	5
K2000-038	1	180	3.5	0	0	1	5
K2000-038	1	180	3.5	q	0	0	5
K2000-038	1	180	7	1	1	0	5
K2000-038	1	240	3.5	0	0	1	5
K2000-038	1	240	3.5	1	0	0	5
K2000-038	1	240	4	0	1	1	5
K2000-038	1	300	5	1	1	0	5
K2000-038	1	300	3.5	0	0	1	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Lake1-004	0	340	nr	nr	nr	nr	5
Lake1-004	0	20	3.2	q	0	nr	5
Lake1-004	0	20	4	q	0	nr	5
Lake1-004	0	20	6	q	0	nr	5
Lake1-004	0	80	nr	nr	nr	nr	5
Lake1-004	0	140	nr	nr	nr	nr	5
Lake1-004	0	200	nr	nr	nr	nr	5
Lake1-004	0	260	nr	nr	nr	nr	5
Lake1-009	1	0	nr	nr	nr	nr	5
Lake1-009	1	60	nr	nr	nr	nr	5
Lake1-009	1	120	5	1	1	nr	5
Lake1-009	1	120	9.5	1	1	nr	5
Lake1-009	1	180	5	1	1	nr	5
Lake1-009	1	180	6	1	1	nr	5
Lake1-009	1	180	4	q	1	nr	5
Lake1-009	1	180	8	q	0	nr	5
Lake1-009	1	240	nr	nr	nr	nr	5
Lake1-009	1	300	nr	nr	nr	nr	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Mist-042	1	0	5	0	0	1	5
Mist-042	1	0	7	1	0	0	5
Mist-042	1	0	3.5	0	0	0	5
Mist-042	1	0	4.5	0	0	1	5
Mist-042	1	0	4	0	0	1	5
Mist-042	1	0	3.5	0	0	1	5
Mist-042	1	0	5	1	0	0	5
Mist-042	1	0	4	0	0	0	5
Mist-042	1	0	9	0	0	1	5
Mist-042	1	0	8	1	0	0	5
Mist-042	1	0	4	0	0	0	5
Mist-042	1	0	5	0	0	0	5
Mist-042	1	60	3	0	0	0	5
Mist-042	1	60	4	1	0	0	5
Mist-042	1	60	6	0	0	1	5
Mist-042	1	60	6	1	0	0	5
Mist-042	1	120	7	0	0	1	5
Mist-042	1	120	3.5	0	0	0	5
Mist-042	1	120	6	0	1	0	5
Mist-042	1	120	8	1	0	0	5
Mist-042	1	120	4	0	0	0	5
Mist-042	1	120	4	0	0	0	5
Mist-042	1	120	3.5	0	0	0	5
Mist-042	1	120	6	0	1	0	5
Mist-042	1	120	4	0	0	1	5
Mist-042	1	180	4	1	1	0	5
Mist-042	1	180	8	0	0	0	5
Mist-042	1	180	6	1	0	0	5
Mist-042	1	180	3.5	0	0	1	5
Mist-042	1	180	4	0	0	0	5
Mist-042	1	180	5	0	0	1	5
Mist-042	1	180	3.5	0	0	0	5
Mist-042	1	240	6	0	0	1	5
Mist-042	1	240	4	1	0	0	5
Mist-042	1	240	7	0	0	0	5
Mist-042	1	240	3.5	0	0	0	5
Mist-042	1	240	7	1	0	0	5
Mist-042	1	240	6	1	0	0	5
Mist-042	1	240	4	0	0	1	5
Mist-042	1	240	3.5	0	0	0	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Mist-042	1	240	8	0	0	1	5
Mist-042	1	300	11	1	0	0	5
Mist-042	1	300	4	0	0	1	5
Mist-042	1	300	5	0	0	1	5
Mist-042	1	300	4	0	0	0	5
Mist-042	1	300	8	1	0	0	5
Mist-042	1	300	11	0	0	1	5
Mist-042	1	300	4	0	0	1	5
Mist-042	1	300	6	0	0	1	5
Mist-042	1	300	6	0	0	1	5
Mist-042	1	300	10	1	0	0	5
Mist-042	1	300	5	1	0	0	5
Mist-043	0	0	8	0	0	1	5
Mist-043	0	0	3.5	0	0	0	5
Mist-043	0	0	6	0	0	0	5
Mist-043	0	0	5	0	0	1	5
Mist-043	0	60	4	0	0	1	5
Mist-043	0	60	8	0	0	1	5
Mist-043	0	60	3.5	0	0	1	5
Mist-043	0	120	4	0	0	1	5
Mist-043	0	120	9	0	0	1	5
Mist-043	0	120	5	0	0	1	5
Mist-043	0	120	5	0	0	1	5
Mist-043	0	180	3.5	0	0	0	5
Mist-043	0	180	4	0	0	1	5
Mist-043	0	180	3.5	0	0	0	5
Mist-043	0	180	3.5	0	0	1	5
Mist-043	0	180	4	0	0	1	5
Mist-043	0	240	4	0	0	1	5
Mist-043	0	240	12	0	0	1	5
Mist-043	0	300	3.5	0	0	1	5
Mist-043	0	300	4	0	0	1	5
Mist-043	0	300	4	0	0	1	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Next-067	1	0	8	1	1	0	5
Next-067	1	60	4	0	0	0	5
Next-067	1	60	4	0	0	0	5
Next-067	1	120	nr	nr	nr	nr	5
Next-067	1	180	nr	nr	nr	nr	5
Next-067	1	240	3	0	0	0	5
Next-067	1	240	note	note	note	note	5
Next-067	1	300	note	note	note	note	5
Next-067	1	300	12	0	1	0	5
Next-067	1	300	3	0	1	0	5
Next-068	0	0	14	1	0	0	5
Next-068	0	0	6	0	0	0	5
Next-068	0	60	nr	nr	nr	nr	5
Next-068	0	120	nr	nr	nr	nr	5
Next-068	0	180	nr	nr	nr	nr	5
Next-068	0	240	nr	nr	nr	nr	5
Next-068	0	300	nr	nr	nr	nr	5
Oak-049	0	0	3.3	0	1	0	5
Oak-049	0	60	nr	nr	nr	nr	5
Oak-049	0	120	nr	nr	nr	nr	5
Oak-049	0	180	nr	nr	nr	nr	5
Oak-049	0	240	nr	nr	nr	nr	5
Oak-049	0	300	6	1	1	0	5
Oak-049	0	300	7	1	0	0	5
Oak-050	1	0	4	0	0	0	5
Oak-050	1	0	4	0	0	0	5
Oak-050	1	60	3.5	0	1	0	5
Oak-050	1	120	3.3	0	1	0	5
Oak-050	1	120	6	0	1	0	5
Oak-050	1	120	4	0	1	0	5
Oak-050	1	120	3	0	1	0	5
Oak-050	1	180	4.5	1	0	0	5
Oak-050	1	180	3.3	0	1	0	5
Oak-050	1	180	5.5	0	1	0	5
Oak-050	1	180	4.5	0	1	0	5
Oak-050	1	240	5	0	0	0	5
Oak-050	1	300	3.5	0	0	0	5
Oak-050	1	300	4	0	0	0	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Sun-053	1	0	3.8	1	1	0	5
Sun-053	1	0	6.8	1	1	0	5
Sun-053	1	60	3.5	0	1	0	5
Sun-053	1	60	7.3	1	1	0	5
Sun-053	1	60	5.5	1	1	0	5
Sun-053	1	120	5	1	1	0	5
Sun-053	1	120	5.5	1	1	0	5
Sun-053	1	120	3.5	0	1	0	5
Sun-053	1	180	15.3	1	1	0	5
Sun-053	1	180	7	1	1	0	5
Sun-053	1	180	16.5	1	1	0	5
Sun-053	1	180	5.8	1	1	0	5
Sun-053	1	180	9	1	1	0	5
Sun-053	1	180	3.5	1	1	0	5
Sun-053	1	180	4.1	1	1	0	5
Sun-053	1	180	10.8	1	1	0	5
Sun-053	1	240	4.3	1	1	0	5
Sun-053	1	240	4.3	1	1	0	5
Sun-053	1	240	3.8	1	1	0	5
Sun-053	1	240	6	1	1	0	5
Sun-053	1	240	5	1	1	0	5
Sun-053	1	300	7.5	1	1	0	5
Sun-053	1	300	6.5	1	1	0	5
Sun-053	1	300	9	1	1	0	5
Sun-054	0	0	5	1	1	0	5
Sun-054	0	0	5.3	1	1	0	5
Sun-054	0	60	5.5	0	1	0	5
Sun-054	0	60	7	1	1	0	5
Sun-054	0	120	nr	nr	nr	nr	5
Sun-054	0	180	4	0	1	0	5
Sun-054	0	180	3.8	0	1	0	5
Sun-054	0	180	5.5	1	1	0	5
Sun-054	0	240	4.5	1	0	0	5
Sun-054	0	240	6.5	1	0	0	5
Sun-054	0	240	6.8	0	0	0	5
Sun-054	0	240	3.5	0	0	0	5
Sun-054	0	300	3.3	0	1	0	5
Sun-054	0	300	3.3	1	1	0	5
Sun-054	0	300	4	0	1	0	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Wet-044	0	0	4.5	0	1	1	5
Wet-044	0	60	3.4	0	1	0	5
Wet-044	0	60	4.5	0	1	0	5
Wet-044	0	60	5	0	0	0	5
Wet-044	0	120	5.8	0	0	1	5
Wet-044	0	180	nr	nr	nr	nr	5
Wet-044	0	240	nr	nr	nr	nr	5
Wet-044	0	300	nr	nr	nr	nr	5
Wet-045	1	0	3.2	0	1	1	5
Wet-045	1	60	6.4	1	0	0	5
Wet-045	1	60	4.8	0	1	1	5
Wet-045	1	60	4.9	0	0	1	5
Wet-045	1	60	4.4	0	0	1	5
Wet-045	1	60	10	0	0	1	5
Wet-045	1	60	3	0	0	1	5
Wet-045	1	120	nr	nr	nr	nr	5
Wet-045	1	180	5	0	0	1	5
Wet-045	1	240	11	1	1	0	5
Wet-045	1	240	3.5	0	0	0	5
Wet-045	1	240	4	0	0	0	5
Wet-045	1	300	nr	nr	nr	nr	5
Who-064	0	0	3.5	0	1	0	5
Who-064	0	60	nr	nr	nr	nr	5
Who-064	0	120	4	0	1	0	5
Who-064	0	120	4	0	1	1	5
Who-064	0	180	nr	nr	nr	nr	5
Who-064	0	240	4	0	1	1	5
Who-064	0	240	3.5	0	1	0	5
Who-064	0	300	4	0	0	1	5

Site	Disease	Bearing	Diameter (in)	Armillaria	Sound	Cut	Slope
Who-065	1	0	6.5	1	0	0	5
Who-065	1	0	3.5	0	1	1	5
Who-065	1	60	7	0	1	1	5
Who-065	1	60	9	1	0	1	5
Who-065	1	60	4	0	0	0	5
Who-065	1	120	17	0	0	0	5
Who-065	1	120	6.5	0	0	1	5
Who-065	1	120	4	0	1	1	5
Who-065	1	180	5	0	1	1	5
Who-065	1	180	5	1	0	0	5
Who-065	1	180	4	0	1	0	5
Who-065	1	180	3.5	0	0	0	5
Who-065	1	180	4	0	1	0	5
Who-065	1	240	3.5	0	1	0	5
Who-065	1	240	4	0	0	0	5
Who-065	1	240	3.5	1	0	0	5
Who-065	1	240	10	1	0	0	5
Who-065	1	240	6	1	0	0	5
Who-065	1	300	5	0	0	0	5
Who-065	1	300	5	0	1	1	5
Who-065	1	300	7	1	0	0	5
Who-065	1	300	6	1	0	0	5

Armillaria: 1- Armillaria was determined to be the cause debris deposition. 0- Armillaria was determined not to be the cause of debris deposition.

Sound: 1- The debris was determined to be sound. 0- The debris was considered rotten.

Cut: 1- The debris had been cut by mechanical means. 0- Debris was not cut.

In all cases "nr" denotes that there was no record for 1000 hr fuels at that location.

Appendix L. Occurrence of standing dead trees.

Site	Disease	Species	Strata	DBH (in)	Class	Armillaria	Sign	Sample Radius (ft)
Air1-033	0	PIPO	m	7	1wof	0	0	50
Air1-035	1	PIPO	m	2.8	3	1	0	37.2
Anne-062	0	nr	nr	nr	nr	nr	nr	37.2
Anne-063	1	PIPO	o	9.9	1wf	1	1	37.2
Anne-063	1	PIPO	o	4	1wof	1	0	37.2
Bert-055	1	PIPO	o	13	2	1	0	37.2
Bert-056	0	nr	nr	nr	nr	nr	nr	37.2
Cow-040	0	nr	nr	nr	nr	nr	nr	37.2
Cow-041	1	PIPO	o	27.7	1	1	1	37.2
Cow-041	1	PIPO	nr	6.5	2	1	1	37.2
Cow-041	1	PIPO	m	4.5	2	1	q	37.2
Grass-060	0	PIPO	m	3.6	2	0	0	37.2
Grass-060	0	PIPO	m	4	2	0	0	37.2
Grass-061	1	PIPO	o	12.3	2	1	1	37.2
Grass-061	1	PIPO	m	3.5	1wf	1	q	37.2
Grass-061	1	PIPO	o	14.2	3	1	1	37.2
Grass-061	1	PIPO	o	9.1	2	1	q	37.2
Grass-061	1	PIPO	o	9.5	3	1	1	37.2
Hill-051	1	PIPO	o	21.8	2	1	1	37.2
Hill-051	1	PIPO	m	4	3	0	0	37.2
Hill-051	1	PIPO	o	18.1	2	0	0	37.2
Hill-051	1	PIPO	m	6.7	3	0	0	37.2
Hill-051	1	PIPO	o	13	3	0	0	37.2
Hill-051	1	PIPO	o	14	3	0	0	37.2
Hill-052	0	PIPO	m	3.1	1wf	0	0	37.2
Hill-052	0	PIPO	m	5.5	1wf	1	0	37.2
Hill-052	0	PIPO	m	4.9	1wf	1	0	37.2
Jenn-057	1	PIPO	o	13.8	1wof	1	1	37.2
Jenn-057	1	PIPO	m	4.3	2	1	1	37.2
Jenn-057	1	PIPO	m	4.5	1wf	1	1	37.2
Jenn-057	1	PIPO	m	3.6	2	1	1	37.2
Jenn-057	1	PIPO	m	5.2	1wof	1	0	37.2
Jenn-057	1	PIPO	m	4	1wof	1	0	37.2
Jenn-057	1	PIPO	m	8.2	2	1	0	37.2
Jenn-057	1	PIPO	m	7.2	2	1	1	37.2
Jenn-057	1	PIPO	m	4.6	2	1	0	37.2
Jenn-057	1	PIPO	o	7.5	3	1	1	37.2
Jenn-058	0	PIPO	m	6	1wof	0	0	37.2

Site	Disease	Species	Strata	DBH (in)	Class	Armillaria	Sign	Sample Radius (ft)
K2000-037	0	nr	nr	nr	nr	nr	nr	20
K2000-038	1	PIPO	q	9.8	2	1	1	37.2
K2000-038	1	PIPO	q	6.8	2	1	1	37.2
K2000-038	1	PIPO	o	21.7	2	1	1	37.2
K2000-038	1	PIPO	q	8	2	1	0	37.2
K2000-038	1	PIPO	q	12.2	2	1	1	37.2
K2000-038	1	PIPO	q	6.7	2	1	0	37.2
K2000-038	1	PIPO	q	9	2	1	0	37.2
Lake1-004	0	nr	nr	nr	nr	nr	nr	50
Lake1-009	1	PIPO	m	8.7	1	1	1	50
Lake1-009	1	PIPO	q	13.7	3	1	1	50
Lake1-009	1	PIPO	q	7.9	3	1	1	50
Lake1-009	1	PIPO	m	7.1	1	1	1	50
Lake1-009	1	PIPO	o	36	3	1	nr	50
Mist-042	1	PIPO	nr	10.3	2	1	0	37.2
Mist-043	0	nr	nr	nr	nr	nr	nr	37.2
Next-067	1	PIPO	o	7.6	2	1	1	37.2
Next-067	1	PIPO	o	6.9	2	1	1	37.2
Next-068	0	nr	nr	nr	nr	nr	nr	37.2
Oak-049	0	PIPO	nr	4	3	0	0	37.2
Oak-049	0	PIPO	m	4.5	1wof	1	1	37.2
Oak-049	0	PIPO	m	3.3	3	0	0	37.2
Oak-050	1	PIPO	m	3.1	1wof	1	0	37.2
Oak-050	1	PIPO	m	3.6	1wof	1	q	37.2
Oak-050	1	PIPO	m	4.7	1wof	1	1	37.2
Oak-050	1	PIPO	m	3.8	1wof	0	0	37.2

Site	Disease	Species	Strata	DBH (in)	Class	Armillaria	Sign	Sample Radius (ft)
Sun-053	1	PIPO	nr	6.8	3	1	q	37.2
Sun-053	1	PIPO	m	5.3	1wof	1	1	37.2
Sun-053	1	PIPO	m	4.1	1wf	1	1	37.2
Sun-053	1	PIPO	o	14.3	1wf	1	1	37.2
Sun-053	1	PIPO	o	12.8	1wof	1	1	37.2
Sun-053	1	PIPO	o	10.5	1wof	1	q	37.2
Sun-053	1	PIPO	o	33.2	3	1	q	37.2
Sun-053	1	PIPO	o	30.3	2	1	q	37.2
Sun-053	1	PIPO	nr	10.6	3	1	q	37.2
Sun-053	1	PIPO	nr	10.7	2	1	q	37.2
Sun-053	1	PIPO	m	6.5	3	1	q	37.2
Sun-053	1	PIPO	m	8.3	1wof	1	1	37.2
Sun-053	1	PIPO	o	11	1wf	1	1	37.2
Sun-053	1	PIPO	m	7.2	3	1	q	37.2
Sun-054	0	PIPO	m	4.2	1wof	0	0	37.2
Sun-054	0	PIPO	m	3.8	1wof	0	0	37.2
Sun-054	0	PIPO	m	4.1	1wof	0	0	37.2
Sun-054	0	PIPO	m	4.8	1wf	0	0	37.2
Sun-054	0	PIPO	m	6.3	3	0	0	37.2
Sun-054	0	PIPO	m	3.8	1wof	0	0	37.2
Sun-054	0	PIPO	m	3.6	1wof	0	0	37.2
Sun-054	0	PIPO	m	4.4	1wof	0	0	37.2
Sun-054	0	PIPO	m	4.1	1wof	0	0	37.2
Sun-054	0	PIPO	m	4.2	1wof	0	0	37.2
Wet-044	0	nr	nr	nr	nr	nr	nr	37.2
Wet-045	1	nr	nr	nr	nr	nr	nr	37.2
Who-064	0	PIPO	o	5.2	1wof	0	q	37.2
Who-065	1	PIPO	m	5.1	2	1	1	37.2

Strata: o- overstory, m-midstory

Class: 1wof- class 1 without foliage, 1wf- class 1 with foliage, 2 class 2, 3- class 3.

Armillaria: 1- Armillaria was determined to be the cause of mortality. 0- Armillaria was not the cause of mortality.

Sign: 1- Signs of Armillaria were observed, 0- Signs of Armillaria were not observed. "q"- likely but not confirmed signs of Armillaria.

Sample Radius: The sample radius was reduced in areas of many snags.

In all cases "nr" means there were no recorded snags at that location.

Appendix M. Canopy closure and general information for each sample location.

Unit	GPS identity	Disease	Site	Date	Collector(s)	Slope	Aspect	Elevation (ft)	Cover 1 (%)	Cover 2 (%)	Cover 3 (%)	Cover 4 (%)
Air1	-033	0	Air1-033	07_02_2011	Njohnson	5	230	1890	29	18	40	38
Air1	-035	1	Air1-035	07_02_2011	Njohnson	5	230	1938	25	17	72	36
Anne	-062	0	Anne-062	08_27_11	Njohnson, Tmiller	5	240	2015	16	23	35	35
Anne	-063	1	Anne-063	08_27_11	Njohnson, Tmiller	5	0	1994	18	26	22	43
Bert	-055	1	Bert-055	08_20_11	Njohnson, CTH	5	100	2150	46	94	70	44
Bert	-056	0	Bert-056	08_20_11	Njohnson, CTH	5	20	2150	21	12	20	11
Cow	-040	0	Cow-040	07_30_11	Njohnson, Tmiller	5	80	1990	22	27	34	30
Cow	-041	1	Cow-041	07_30_11	Njohnson, Tmiller	5	35	1938	32	39	49	50
Grass	-060	0	Grass-060	08_28_11	Njohnson, Tmiller	5	15	1900	29	21	23	30
Grass	-061	1	Grass-061	08_28_11	Njohnson, Tmiller	5	200	1820	71	38	63	51
Hill	-051	1	Hill-051	08_20_11	Njohnson, CTH	5	250	2050	23	22	30	45
Hill	-052	0	Hill-052	08_19_11	Njohnson, CTH	5	200	2125	32	34	49	24
Jenn	-057	1	Jenn-057	08_21_11	Njohnson, CTH	5	280	2125	28	60	66	17
Jenn	-058	0	Jenn-058	08_21_11	Njohnson, CTH	5	270	2200	11	4	3	5

Unit	GPS identity	Disease	Site	Date	Collector(s)	Slope	Aspect	Elevation (ft)	Cover 1 (%)	Cover 2 (%)	Cover 3 (%)	Cover 4 (%)
K2000	-037	0	K2000-037	07_03_11	Njohnson	5	210	2073	7	4	7	14
K2000	-038	1	K2000-038	07_03_11	Njohnson	5	210	2050	68	76	94	94
Lake1	-004	0	Lake1-004	6_10_2011	Njohnson	5	280	1883	13	34	40	18
Lake1	-009	1	Lake1-009	6_12_2011	Njohnson	7	260	2081	26	31	56	24
Mist	-042	1	Mist-042	07_31_11	Njohnson, Tmiller	5	180	2028	22	21	12	7
Mist	-043	0	Mist-043	07_31_11	Njohnson, Tmiller	5	150	2015	7	9	13	11
Next	-067	1	Next-067	08_28_11	Njohnson, Tmiller	5	50	1915	51	44	54	60
Next	-068	0	Next-068	08_28_11	Njohnson, Tmiller	5	270	1900	33	41	32	38
Oak	-049	0	Oak-049	08_19_11	Njohnson, CTH	5	200	2250	4	6	7	16
Oak	-050	1	Oak-050	8_19_11	Njohnson, CTH	5	206	2280	38	31	16	35
Sun	-053	1	Sun-053	08_21_11	Njohnson, CTH	5	100	2010	47	87	84	72
Sun	-054	0	Sun-054	08_21_11	Njohnson, CTH	5	100	2050	11	14	3	10
Wet	-044	0	Wet-044	07_31_11	Njohnson, Tmiller	5	0	1850	18	14	34	17
Wet	-045	1	Wet-045	07_31_11	Njohnson, Tmiller	5	0	1828	91	39	28	95
Who	-064	0	Who-064	08_27_11	Njohnson, Tmiller	5	138	1990	24	28	31	21
Who	-065	1	Who-065	08_27_11	Njohnson, Tmiller	5	120	1990	38	36	25	26

Cover – Four measurements of percent overstory canopy closure.