Forest Health Assessment and Forest Management Practices Recommendations

City of Bremerton

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WASHINGTON

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Acknowledgements

Gregory Ettl for his invaluable support, advisement, and mentorship throughout the entirety of this project. Michelle Agne for her expertise and advice on pathogen identification and forest management. Robert Edmonds for his pathogen expertise, relevant literature, and assistance with identification. Shawn Behling for her help with ArcGIS. Jonathan Batchelor for his expertise with remote sensing and methodology experience. Ernesto Alvarado for his guidance on fire risk assessment and field equipment use. Samuel Castro and Hannah Farrell for their contribution to the fire risk assessment. Morris Johnson for his expertise and management advice on fire prevention. Ashley Semler for her technical editing and support throughout this project. Brian Harvey for introducing this project. Teresa Smith, Dave Denis, Cami Apfelbeck, Kathleen Cahall, and the City of Bremerton for their experience with the area and inception of this project.

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June 2019

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In conjunction with the City of Bremerton

For completion of Master of Forest Resources Final Project

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1. INTRODUCTION

1.1 Objectives

The objective of this document is to provide the City of Bremerton (City) with forest management recommendations to maintain drinking water quality in Bremerton's Union River Watershed (watershed). The City seeks forest management observations and recommendations for the watershed to provide the most optimal drinking water quality now and into the future. The City is concerned with ensuring the resilience of the forests of the watershed under possible climate and ecological changes and seeks to reduce and to minimize forest pest invasion and forest fire susceptibility.

This report provides forest stand information and landscape-scale management guidance to maximize water protection in the watershed. The primary forest health concerns are addressed in forest delineation (i.e., forest stand boundaries) within this report, including digital maps of forest health attributes (Appendix A). Forest health issues addressed include forest pathogens (primarily laminated root rot fungi [*Coniferiporia sulphurascens*]) and susceptibility to climate change, specifically fire risk.

University of Washington Master of Forest Resources student Luke Semler worked with City staff and University contacts to delineate potential threats to the water supply and offer recommendations for alternative management strategies. Management alternatives and forest health inventory information from previous reports have served as a starting point to identify forest health issues and forest management constraints within the watershed. Forest stewardship planning and recommendations are targeted for Bremerton Public Works & Utilities managers and staff.

1.2 Background

The City owns approximately 3,000 acres surrounding the headwaters of the Union River Reservoir. The reservoir forms behind Casad Dam (built in 1957), has a capacity of 4,000 acre-feet, and provides 60% of Bremerton's drinking water supply. This source provides exceptional water quality and quantity and is one of the few approved unfiltered surface water supplies in the United States. The protected forested watershed essentially acts as filtration for the water supply. To remain unfiltered, the City must consistently comply with strict federal and state requirements for watershed control, source water quality, operation, and disinfection.

In 1938, a large fire destroyed over half of the trees in the watershed resulting today in a moderately monoculture stand of 80-year-old trees, predominantly Douglas-fir (*Pseudotsuga menziesii),* with some western hemlock (*Tsuga heterophylla*) in the upper elevations, and some red alder (*Alnus rubra*) in the lower elevation and wetter areas.

Protection of drinking water resources has been the paramount forest management priority in the watershed. Forest land management plans and inventories were prepared for the watershed in 1986, 1996, and 2006. Harvest is limited within the hydrologic boundary of the Union River water supply (see the blue outline of the drainage basin on Map 1 in Appendix A) compared to other City utility lands where harvest is not limited. Over the past 25 years, there has been a removal of trees with laminated root rot and wind-blown trees, and some even-age harvesting on the edges of the watershed. A separate watershed management plan identifies required protection activities in compliance with the Safe Drinking Water Act Surface Water Treatment Rule.

1.3 Forest Stand Information

The topography of the property is undulating at most locations, with frequent drainages and substantial elevational changes across the broad landscape. Varied slope and aspect are part of the complex geology of the property. Soil types include: Grove very gravelly sandy loam, Indianola-Kitsap complex, Kapowsin gravelly ashy loam, Kilchis very gravelly sandy loam, Kilchis-Shelton complex, Kitsap silt loam, McKenna gravelly loam, Ragnar fine sandy loam, Schneider very gravelly loam, and Shelton very gravelly sandy loam (NRCS n.d.). The various animal species encountered throughout site visitation and field data collection are typically and indicative of a functioning terrestrial ecosystem. Many locations within the assessed property contain an elevated forest canopy structure separate from a well-developed recalcitrant understory component. Other portions of the property consist of continuous vertical continuity between shrub vegetation and forest canopy, which provides more structural diversity but also poses a threat to catastrophic forest crown fire and forest cover loss (see Photograph 11 in Appendix C). Forest regeneration is occurring naturally with components of various native, and in some cases, invasive, species. Dominant tree species across the property are a mostly uniform cohort of Douglas-fir (*Pseudotsuga menziesii*), which is typical for the region, age, and disturbance regime of stand-replacing fire events. In addition to the primary forest species cover of Douglas-fir (*Pseudotsuga menziesii*), forested stands include mixed age and species cohorts of western hemlock (*Tsuga heterophylla*) (some trees were observed to be exhibiting symptoms of the forest pathogen hemlock dwarf mistletoe [*Arceuthobium tsugense*]), bigleaf maple (*Acer macrophyllum*), western redcedar (*Thuja plicata*) (in moist sites), Pacific madrone (*Arbutus menziesii*), and black cottonwood (*Populus trichocarpa*) (at one moist site). Western white pine (*Pinus monticola*) was observed on the property during site visitation and field data collection as a planted species after an artificial regeneration harvest targeted to remove laminated root rot. The planted western white pine (*Pinus monticola*) exhibited symptoms of the forest pathogen white pine blister rust (*Cronartium ribicola*) on the branching structures. Union River Watershed Forester, Dave Denis, noted observing (one) grand fir (*Abies grandis*) within the watershed, in addition to the above-listed species components. It is also expected that Pacific yew (*Taxus brevifolia*) exists within the property and multiple have been observed by Dave Denis. Dominant understory vegetation consisted of species: evergreen huckleberry (*Vaccinium ovatum*) and salal (*Gaultheria shallon*). Associated understory cover species chiefly consisted of species: western swordfern (*Polystichum munitum*), bracken fern (*Pteridium aquilinum*), oceanspray (*Holodiscus discolor*), red huckleberry (*Vaccinium parvifolium*), short/dull Oregon-grape (*Mahonia nervosa*), Pacific rhododendron (*Rhododendron macrophyllum*), Indian plum (*Oemleria cerasiformis*), and Nootka rose (*Rosa nutkana*). Invasive species encountered included: Scotch broom (*Cytisus scoparius*), Himalayan blackberry (*Rubus armeniacus*), and English holly (*Ilex aquifolium*). The diversity of vegetation is important to ecosystem structure, function, and future management options. In some locations, invasive species dominate, and while they alter the vegetation communities they may not alter ecosystem function in relation to water quality or quantity. In some cases, they may be a key component in stabilizing slopes.

2. FOREST HEALTH ISSUES

Forest health is important for ecosystem services, especially for the provision of clean drinking water. Forest ecosystems have a direct relationship with forest pathogens and other disturbances that contribute to tree mortality. Tree mortality within the watershed poses a risk to slope and soil stabilization, which proves a risk to increased levels of water turbidity. For the watershed to remain unfiltered and to reduce the likelihood of constructing a water treatment plant, to mitigate turbidity issues, forest pathogenic agents and forest fire risk must be minimized. Forest health issues are important now more than ever with climate changes that provide uncertainty in understanding how health issues will affect a future forest.

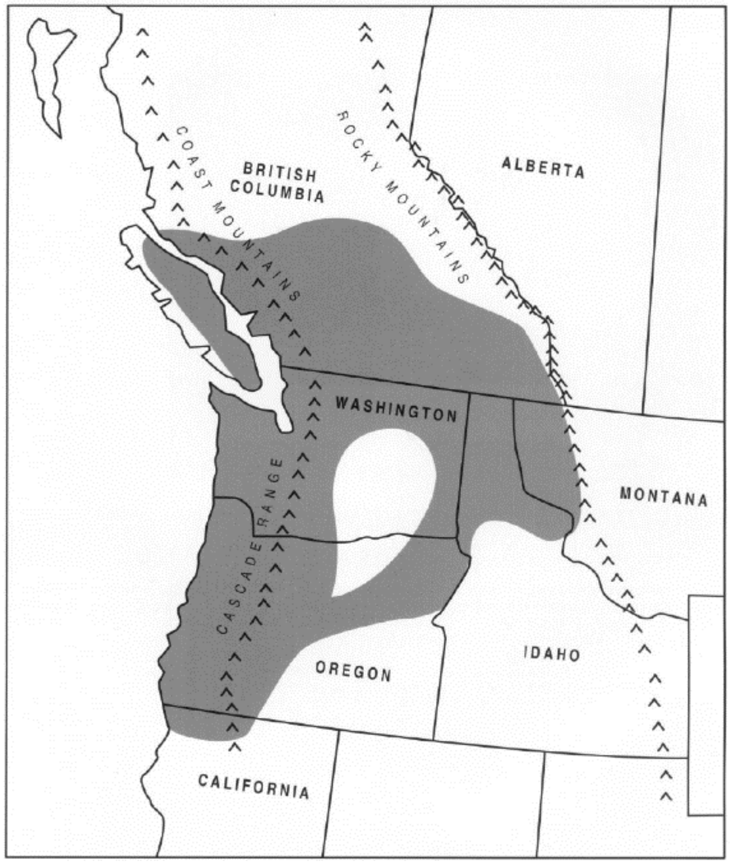
2.1 Forest Pathogens: Laminated Root Rot

2.1.1 Background

Forest pathogens are important in ecological function as they can select for species and/or genetic variation and allow for species diversity. The death of a live tree can contribute many positive aspects to forest health when pathogens are not widespread. Trees that are killed are often weakened from another agent or stressing factor, suppressed from competition, and/or may be outside their typical range of environmental conditions. In addition to natural selection improving the fit of remaining individuals within a population, dead trees provide habitat for forest biota, and the addition of available light allows for species diversity within the forest stand. However, under outbreak conditions, pathogenic agents may be cause for concern; complete forest cover loss coupled with the possibility of the long-term conversion to a non-forested site. Due to the risk of deforestation, large-scale pathogenic outbreaks should be monitored and prevented by forest managers who have a priority objective to maintain forest cover. A single pathogenic agent may not be the sole driver of tree mortality, but a widespread pathogen often exhibits stress upon trees, attracting additional pathogens to vulnerable trees, raising the probability of large-scale mortality.

According to the Washington State Academy of Sciences (WSAS 2013), the three major root diseases of most concern for Washington forests are Armillaria root rot, Heterobasidion root and butt rot, and laminated root rot (*Coniferiporia sulphurascens*). Armillaria root disease is caused by one or more of several biologically distinct fungal species of Armillaria. Armillaria is a genus of pathogenic disturbance agents native to the area and is an important part of ecosystem function and a driver of diversity through tree mortality. Armillaria has a global presence, occurring on both gymnosperm (mainly evergreen) and angiosperm (mainly deciduous) tree forms. Although the root pathogen is capable of long-term persistence, it has been found to mainly correlate to land management practices regardless of the site (Alexander, Shearer, and Shepperd 1990; McDonald, Martin, and Harvey 1987) advancing by centimeters to meters from a colonized stump. Heterobasidion root and butt rot is caused by the fungus *Heterobasidion annosum* (now *H. occidentale* and *H. irregulare*). Heterobasidion is also a driver of conifer mortality (primarily on western hemlock but can also occur on Douglas-fir [Edmonds 2019]) and is prevalent throughout North America but also has a global impact on forests. (WSAS 2013)

Laminated root rot, caused by *C. sulphurascens* and *C. weirii* (until recently, referred to as *Phellinus sulphurascens* and *Phellinus weirii*), occurs throughout temperate Asia and Russia; however, within North America, the pathogen is confined primarily to the Pacific Northwest, occurring from Canada to northern California (see Figure 1 below). The term laminated root rot refers to both species *C. sulphurascens* (affecting most fir trees native to the Pacific Northwest) and *C. weirii* (affecting primarily western redcedar [*Thuja plicata*]). All hardwoods are immune to both *C. sulphurascens* and *C. weirii*. For a complete list of native susceptible species see Appendix B of this report. (WSAS 2013)



Source: Thies and Sturrock 1995

Figure 1: Laminated Root Rot Distribution

C. sulphurascens can live both parasitically, colonizing the live bark and cambium of its hosts, and saprophytically, in the wood of dead trees and stumps left after harvest. Once the fungus has penetrated bark tissues, it kills phloem and cambial tissues, and initiates decay in the xylem, advancing progressively into the heartwood and up the tree stem. All scientifically reliable sources (USDA 2017; WSAS 2013; Harrington and Thies 2007; Thies and Sturrock 1995; Nelson, Martin, and Williams 1981) agree that the pathogen is capable of progressing at a maximum 12 inches per year. Once infected trees die or are removed, *C. sulphurascens* retreats from the surface of infected roots, leaving behind endotrophic mycelia. Typically, the fungal pathogen resides in the stump until a new host root grows to an infection while the pathogen inoculum is restricted to the rhizosphere (root-zone). (WSAS 2013)

The ultimate causal agent for tree mortality is not always apparent and is often convoluted by multiple agents driving mortality over the life history of the tree (Franklin, Shugart, and Harmon 1987). Understanding of the driving factors to the decline of the forest is imperative so that detrimental effects may be effectively understood and managed. (Thies and Sturrock 1995; WSAS 2013)

Compounding complicated mortality assessments, other common forest pathogens for the region are Douglas-fir pole beetles and/or Douglas-fir engravers, which commonly attack smaller and laminated root rot infected trees, while larger Douglas-fir (*Pseudotsuga menziesii*) with a laminated root rot infection are commonly killed by Douglas-fir bark beetles, thus multiple pathogens influence tree mortality. Laminated root rot infection causes the conifer to exude pheromones that attract these coevolved biotic mortality agents (Aukema et al. 2016). Additionally, where fire exclusion is most successful, there is an increase in the proportion of shade-tolerant, susceptible conifers and concurrently in the amount of laminated root rot. (Thies and Sturrock 1995; WSAS 2013)

2.1.2 Treatment

Understanding treatment methods to control laminated root rot demonstrates possible treatments which could be implemented within the watershed. A historical review of published treatments against the fungal pathogen can also provide a reference and example for treatment success and effectiveness. Forest science treatment methods for laminated root rot include using a chemical application to genetic engineering (WSAS 2013)

In the early 1970s, results from field trials suggested laminated root rot inoculum could be reduced by high dosages of nitrogen fertilizer. These field studies continue, but it is anticipated that fertilization will not have a significant impact on the incidence of laminated root rot because results showed that while fertilizer application increased growth rates, it failed to prevent most incidences of seedling mortality. (Thies and Sturrock 1995; WSAS 2013)

In an exploration of natural resistance to laminated root rot, scientists concluded a 10,000-year coexistence, since the time of the last ice age, is too short of a time for natural variation and selection pressures to generate and establish resistant phenotypes, considering that each natural rotation of Douglas-fir (*Pseudotsuga menziesii*) often takes centuries, and selection pressures may be low or intermittent. However, it may be possible to enhance Douglas-fir (*Pseudotsuga menziesii*) resistance through genome modification by a customized transcription activator-like effector (TALE) protein. TALEs are DNA-binding proteins and the mechanism by which plant pathogenic bacteria counter the defenses of their host. Because of the protein architecture of TALEs, it is possible to construct artificial effectors for almost any specificity. This specificity of TALEs has been used to modify genomes of crops, livestock, and embryonic stem cells without the use of recombinant DNA methods. From these successes, TALEs should also be considered for their potential to reduce the susceptibility and/or enhance the resistance of Douglas-fir (*Pseudotsuga menziesii*) to laminated root rot and possibly other root diseases. Research has been conducted and is ongoing for laminated root rot resistance in Douglas-fir (*Pseudotsuga menziesii*) by the Stand Management Cooperative (SMC) and by British Columbia, Canada. (WSAS 2013)

Trichoderma viride, and other species in this genus, are well-documented fungi that act as biofungicides to wood decay fungi, which suggests promise for their use as biological control agents for laminated root rot (Nelson 1973; Nelson 1964). An experiment introduced *Trichoderma viride* into holes bored in laminated root rot-infested stumps, which colonized the diseased wood immediately around the introduction holes. However, suitable virulent antagonists must be found that are capable of rapid colonization of laminated root rot-infested stumps and roots. Systems have not yet been developed for proper handling and introduction of antagonists into stumps, and treatments must be developed to enhance the activity of antagonists, making this approach currently impractical. (Thies and Sturrock 1995)

A 2007 U.S. Department of Agriculture (USDA) Forest Service study on pathogen treatment by fumigant injection researched the effectiveness of fumigant control in the northern Oregon Coast Range. Chloropicrin (trichloronitromethane) fumigants were applied by inserting them into holes drilled into the base of live trees with the treatment applying the lowest dosage of chloropicrin having higher tree survival rates than the untreated control. Vascular cambium (live tree tissue) death around the injection sites was observed, and although healing over the damage was common, some cases of fluting occurred (chiefly in the high dosage experiments). However, only a 9% reduction in fungal survival by injecting stumps infected was observed in this case. At equivalent or even much lower dosages, chloropicrin and Vorlex (20% methyl isothiocyanate [MITC], 80% chlorinated C3 hydrocarbons) had more negative effects on tree growth and survival than MITC. MITC increased survival of infected trees and even at low dosages was effective in reducing laminated root rot levels in infected root systems without causing significant growth reductions. Documentation of tissue damage suggests that fumigant application during the dormant season might result in less cambial damage than a spring application. (Harrington and Thies 2007)

Chemical inactivation of *C. sulphurascens* inoculum with fumigants has thus been demonstrated and the U.S. Environmental Protection Agency approved a label allowing the use of chloropicrin to reduce inoculum of laminated root rot in Douglas-fir (*Pseudotsuga menziesii*) stumps in 1989 (Thies and Sturrock 1995), but fumigants do not penetrate sufficiently into buried roots to adequately eliminate this pathogen. Additionally, due to the cost and restrictive regulatory policies about the use of pesticides in forests and watersheds, fumigation likely will remain limited to control of seedling pathogens in nurseries. (WSAS 2013)

The USDA Forest Service notes that viable forest prescription applied treatment exists and is practiced on federal lands via the creation of an infection buffer of 15 meters from the center of an infection (USDA 2017). This buffer includes the removal of susceptible species and replanting of resistant/immune species such as red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), and western redcedar (*Thuja plicata*), which are planted to eliminate a laminated root rot infestation (USDA 2017; Thies and Sturrock 1995). Follow-on maintenance of precommercial thinning of in-seeded susceptible species periodically is recommended (USDA 2017). Non-hosts must remain the only species on site for at least 50 years to remove inoculum (USDA 2017). The infected wood unable to be sold to market on federal lands is often used for riparian restoration because the addition of large woody detritus into streams provides habitat for endangered Washington State salmon (USDA 2017). Stump removal is an effective control method but is normally limited to slopes less than 30% due to harvest equipment constraints (WSAS 2013). Trenching 12 inches wide by 18 inches deep has been shown to effectively buffer the laminated root rot infected sites, allowing for artificial regeneration of susceptible species in adjacent sites (Thies and Sturrock 1995).

If the pattern of laminated root rot infection is diffuse rather than aggregated, forest openings, caused by tree loss, do not accurately portray the distribution of the disease. A management strategy that assumes clumped inoculum distribution is unlikely to yield the desired results if a distribution is diffuse. Natural succession may provide a long enough time duration for laminated root rot inoculum to be rendered ineffective before host species reoccupy the site. (Thies and Sturrock 1995)

2.2 Susceptibility to Climate Change: Fire Risk

2.2.1 Background

Historical evidence of disturbance regimes provides information on what future disturbances we can expect. Climate change has made disturbance regimes more unpredictable, and therefore, threat preparation is not as certain to be successful as it was historically. Currently, the best strategies are to prepare for conditions that we know and understand while allowing for increased future options for land managers.

Historical documentation derived from dendrochronological analysis, lakebed sediment cores, and chronological histories constructed for the region show a general pattern of stand-replacing fire events since the last ice age, roughly 10,000 years ago (Dale et al. 2001). Anthropogenic carbon emissions have posed a new threat to this disturbance regime that organisms and their ecosystems have adapted to and evolved with. As atmospheric carbon concentrations increase, it is predicted that disturbance regimes are also expected to change (Dale et al. 2001). Altered disturbance regimes from climate change are expected to have interactions with the altered fuel quantities due to the past century of fire exclusion (Agee 1998; Dale et al. 2001). Model predictions show that the region should expect more frequent fire events due to climate change (Dale et al. 2001; Hessl 2011; Sheehan, Bachelet, and Ferschwiller 2019).

West of the Cascade Range in Washington State, the dominant source of forest disturbance is stand-replacing fire events (Agee 1998). Large catastrophic fire events in the region consume tree crowns and remove the live trees from the forested landscape, providing an opportunity for natural regeneration and producing a new generation of forest (Agee 1998). Large disturbance events, such as crown fires, allow for ecosystem successional diversity and are an important piece of the landscape lifecycle (Turner et al. 1998; Harvey, Donato, and Turner 2016). Many species that thrive in early seral conditions specialize in this ecotype (Harvey and Holzman 2013).

Westside forests fires have, for the past 100 years, typically been extinguished quickly due to rapid detection, preventing large-scale stand-replacing fire events (Agee 1998). Because of a series of severe fires in the early 1900s, the general public became acutely aware of the danger wildfires posed for rural communities. The USDA Forest Service adopted a firm anti-fire stance that resulted in widespread suppression throughout the western United States. This policy has caused fuels to build up, particularly across the western United States, further increasing the risk that ignition will result in a large uncontrolled fire.

Lightning has been the largest source for ignition of the fire events of the region (Krock 2002; Scott et al. 2014); however, this is not currently the case for the Bremerton watershed. Interviews with land managers have revealed that human-caused fires have been the source of ignition in the property for at least the last five years. Both methods of ignition, lightning and anthropogenic, pose the same threat of catastrophic forest cover loss; however, lightning storms are monitored, expected, and can provide for more rapid deployment of control methods when compared to unpredictable human ignitions when fire events are of highest concern during dry forest conditions. Rapid detection is crucial for firefighter control and prevention of large-scale forest loss.

2.2.2 Treatment

Flaming fronts have a proclivity to move in the direction with the wind. Therefore, the regional prevailing wind direction, but more importantly the anomalous dry east wind, is important to understand to implement fire safety practices. In Washington State, the prevailing wind direction is southwesterly (WRCC 2019). Historical large fires in the region, such as 'The Big Burn' (of 1910), ignited east of the crest of the Cascade Range and moved over the mountain range due to a dry easterly wind, in contrast to the typical southwesterly wind. This wildfire burned about three million acres and killed eighty-seven people, including seventy-eight firefighters (Diaz and Swetnam 2013). This continental wind tends to dry large areas of the landscape increasing the risk for a landscape-level catastrophic fire. The City should be cognizant of forest moisture conditions and wind direction in the watershed to assist with fire detection and extinction.

In addition to the rapid detection of fire, other control methods have proven effective to mitigate fire risk. Forest thinning has been shown to reduce the risk of total forest cover loss through disruption of crown continuity (Graham et al. 1999). Fire breaks (human-made forest gaps to prevent fire movement) have also demonstrated an effective means of protection, but widths of fire breaks can depend on forest fuels loading, vegetation type, regional climate, and weather patterns. By creating divisions in live fuels and fallen debris, crown to crown spread is slowed significantly and new fires are more easily isolated to individual sections of forest. Personal correspondence with experts in the field suggest that west of the Cascade Range a fire break width of at least two tree heights (Ettl 2019; Johnson 2019) may be required to prevent fire from crossing the fire break; this minimal break, removing as little from the landscape as possible while providing a place to fight fire.

3. METHODOLOGY

3.1 Laminated Root Rot

A combination of aerial photography and field reconnaissance was used to assess forest health and forest fuel concerns. Thirty 15-meter transects (standard practice as identified by Thies and Sturrock 1995) were established from May 17 through May 20, 2019, by Luke Semler, across 10 randomly assigned plots extending, on average, 150 meters from the most recently mapped infection centers (Map 2 in Appendix A) within the City's watershed to examine the prevalence and extent of laminated root rot. The sites spanned elevational gradients while covering a range of stand structure, topographic positions, and mortality levels (Map 1 in Appendix A). Each of these plots was also used to assess the risk of catastrophic stand-replacing fire events for fuel load calculations using a 20-meter transect. At each site, azimuths were randomly assigned to establish transect direction.

Along each transect, conifer health was assessed through aboveground stand examination, root collar excavation, and evaluation. Digital images of ectotrophic mycelial fans, forest structure, individual suspected infected trees, stumps, and large woody detritus were shared with forest pathogen experts for verification. Every conifer within 2 meters of each transect line was evaluated using the above methods. The aboveground assessment included determination of a stress cone crop and/or thin, yellow, and reduced crowns. Often trees lose structural integrity and trees are toppled by wind (windthrow) before crown symptoms are apparent. Forest and tree crowns were observed for reduced height growth with rounded tops, bushy branch ends, and/or shortened needles with most needles near branch ends (Thies and Sturrock 1995). It is important to note that a tree more than 60 years old may have a normal appearing crown but have a substantial portion of its root system infected with laminated root rot, and crown symptoms are likely to be expressed earlier on a poor site than on a good site (Thies and Sturrock 1995). (Nelson, Martin, and Williams 1981) Photographs taken during site visitation and data collection are included in Appendix C (some textbook examples are also provided for comparison).

Although the property was examined for prevalence of laminated root rot sporophores (the spore-bearing structure of a fungus), these are rarely seen in the field; aerial detection is the best characteristic way to identify rot pockets (Nelson, Martin, and Williams 1981). Historical maps and current aerial photograph images were printed at high resolution and examined using referenced site collected data and apparent visual patterns over the property. In addition, to assess for ectotrophic mycelial fans, callus roots were also surveyed. Callus roots may form as a protection mechanism of the root system where adventitious roots may sprout from (Thies and Sturrock 1995).

Forest structure of laminated root rot infected sites often consists of angiosperm development; for example, patches of bigleaf maple. Laminated root rot can be identified on living infected trees by carefully brushing away the soil and examining the root collar and lateral roots for superficial (ectotrophic) mycelia. Typically, the mycelia are grey-white to tawny to light purple and form a continuous sheath around the outer surface of infected roots with thin bark, often binding soil particles to the roots (see Photograph 10 in Appendix C). A brown (or black if old), crust-like mycelial growth often can be found over a felt of setal hyphae mixed with superficial mycelia on the bark below the duff layer. Mycelial growth is particularly noticeable in between roots near the trunk or in deep bark crevices. The crust is most easily found at the root collar and at root crotches but is also common on the undersides of roots and stumps. In trees with thick root bark, the endotrophic mycelia containing setal hyphae are sometimes not evident on the bark surface but are found in pockets within the bark. (Thies and Sturrock 1995)

3.2 Fire Risk

In addition, data for fire assessment was also collected: slope (using a clinometer), aspect (using a compass), and stand basal area through point sampling (using a Spiegel Relaskop). Stand density was then calculated in the laboratory. Height to live crown was also measured using the Relaskop. Surface fuel loads were calculated using collected plot data using a go-no-go gauge and calipers including litter and duff measurements (using a precision ruler) along transect lines. Fuel loads were then calculated in the laboratory using software programs BehavePlus 6.0.0 and USDA Forest Service Fuel Characteristic Classification System (FCCS) 3.0. A copy of the Surface Fire Behavior Report is included in Appendix D.

4. FINDINGS

4.1 Laminated Root Rot

Laminated root rot inoculum/evidence was found at every site (see Map 2 in Appendix A and comparison photographs in Appendix C). Many Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) were asymptomatic; however, infected stumps were prevalent throughout the property. Evidence of laminated root rot was also widespread on downed logs, and various stages of inoculum viability were found at root collars at all inspection points (Map 2 in Appendix A) indicative of diffuse laminated root rot distribution. Although other pathogenic agents were examined for throughout the watershed, consultation with a forest pathology expert for the region noted that *Leptographium wageneri* (black stain root disease) and *Phaeocryptopus gaeumannii* (Swiss needle cast) should not be of great concern for the watershed land managers because *Leptographium wageneri* is problematic on sites drier than those within the watershed and *Phaeocryptopus gaeumannii* tends to not cause large mortality events in the region. Armillaria root rot was not observed on the property at any of the sample locations. Western hemlock individuals experiencing mortality from breakage may be caused by Heterobasidion root and butt rot (Edmonds 2019). Laminated root rot creates conditions for and attracts pathogenic insects; however, outbreaks of these insects are typically confined to local scales and homogenous stands of even age and species. No evidence of pathogenic insects was observed.

The forested area surrounding the drainage immediately below the Casad Dam exhibited clear evidence of laminated root rot infection (see Photograph 7 in Appendix C). *Pseudotsuga menziesii* individuals and small pockets showed crown dieback indicative of the disease, while *Thuja plicata* within this area appeared completely healthy and had no evidence of ectotrophic mycelia on the surface of excavated roots. Laminated root rot root collar inspection of *P. menziesii* verified appearance suspicions (see Photograph 10 in Appendix C), coupled with lamination, brakeage, and root tip up mounds completed the verification process that was conducted at each of the assessment locations.

At the locations where tree saplings were not exhibiting signs or symptoms of laminated root rot, there was evidence of nearby inoculum within the duff layer and infections in neighboring *Pseudotsuga menziesii*. An image of a freshly cut stump was collected (Appendix C) and although laminated root rot fungi were observed at the root collar, the wood did not appear to have characteristic stain, which was confirmed by Robert Edmonds, a University of Washington Emeritus Professor of forest pathology. This information reveals that although the prevalence of laminated root rot is diffuse throughout the property, not all sites have trees that are currently experiencing morality from the infection and infections may not yet be penetrating into the tree stem.

Throughout the property there was an unidentifiable tree symptom that was exhibited; some mature *Pseudotsuga menziesii* that had lost a limb, apparently from breakage, clearly had a black substance on the lost-limb scar. The wounded sites of these trees did not appear to be healing, although the breakage may have been too recent for tree self-repair. The trees that had this substance did not appear to be emitting sap or resin from the wound sites. The black substance appeared to be a mold or fungal crust, possibly a canker fungus (Edmonds 2019). The prevalence of this black substance on wounded trees was not concentrated in any area and less than 10 trees were observed with this condition throughout the property. The black substance was observed below the height of the live crown but above 1.37 meters diameter at breast height (DBH).

4.2 Fire Risk

Stand density helps understanding of forest fire behavior and intensity and provides a baseline for thinning targets in the recommendations section of this report. Stand density was calculated as 45.57 basal area meters squared per hectare (198.5 feet squared per acre) overall for the property. Average DBH for the trees measured on the property was calculated to be 44.14 centimeters. Average height to live crown was calculated to be 18.41 meters; however, for fuels assessment, it is important to note vertical continuity from surface fuels to canopy was present at some of the sites.

Fuel load calculations help describe potential fire behavior and intensity predictions. Fuel load modeling calculations were performed using collected field data, and inputs for BehavePlus were used to calculate two models: one for late spring and one for late summer. Late summer models were performed to demonstrate worst-case-scenario situations for wildfire exemplifying dry forest conditions coupled with high winds of 32.2 kilometers per hour. Fire behavior models were also calculated using FCCS, which provides for greater information inputs, producing a generalized model for wildfire. FCCS inputs did not have the seasonal variability that BehavePlus did. BehavePlus spring model surface fire rate of spread equated to 2.7 meters per minute with a surface fire flame length of 1.5 meters. BehavePlus dry forest conditions with high winds model surface fire rate of spread was calculated to be 18.8 meters per minute with a surface fire flame length of 3.8 meters. FCCS surface fire rate of spread calculated 3.35 meters per minute with a flame length of 3.54 meters (averaging two Douglas-fir [*Pseudotsuga menziesii*] forest types present in the property).

5. RECOMMENDATIONS

The following landscape-level management guidance represents silvicultural possible pathways for implementation at the watershed. Implementation of all options is a possibility if time and financing allow. Prescription options are optimized for objective maximization using the best known effective treatments and variabilities for decision-makers. Conducting all treatments below does not guarantee removal of laminated root rot or fire from the property but will best prepare the forest for an uncertain future.

5.1 Laminated Root Rot

5.1.1 Option 1

Allow natural succession to progress through forest decay phases and natural forest species restructuring. Species conversion will likely occur over a vast time period, but will, in most stands with a dominant recalcitrant understory, result in a vegetation cover consisting mainly of native and invasive shrub species. This option contains a (minimal) risk in slope instability due to the difference of root penetration depth of shrub species to tree species, which may increase water turbidity levels. In hardwood stands, predominantly red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*), the cohort is expected to survive to roughly age 100 before most of the stand experiences mortality, with regeneration species uncertain, but likely native. Red alder (*Alnus rubra*) sometimes nitrifies the soil, increasing acidity, to a condition where red alder (*Alnus rubra)* is unable to persist, but more importantly and often provides for conditions optimal to Pacific Northwest coniferous species recolonization where natural regeneration is probable after laminated root rot inoculum is rendered inactive.

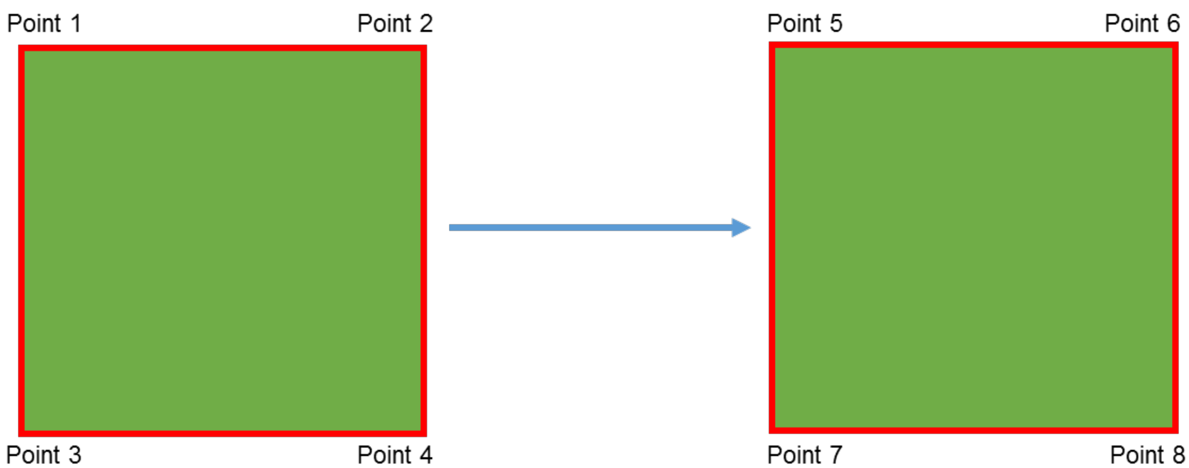
5.1.2 Option 2

Perform a final harvest for the watershed where possible for species conversion, removing all Douglas-fir (*Pseudotsuga menziesii*) and grand fir (*Abies grandis*) (Thies and Sturrock 1995). To reduce persistence of laminated root rot and to allow for future managers to have a wider range of options, managers should consider removal of all, if encountered during final harvest, mountain hemlock (*Tsuga mertensiana*), Pacific silver fir (*Abies amabilis*), Engelmann spruce (*Picea engelmannii*), noble fir (*Abies procera*), Pacific yew (*Taxus brevifolia*), Sitka spruce (*Picea sitchensis*), subalpine fir (*Abies lasiocarpa*), western hemlock (*Tsuga heterophylla*), and western white pine (*Pinus monticola*). Although *Tsuga heterophylla* may prove to be resistant to killing by laminated root rot, it often develops extensive butt rot (Thies and Sturrock 1995). Due to their resistance to laminated root rot, final harvest should take precaution to maintain any components of species: western redcedar (*Thuja plicata*), Alaskan yellow cedar (*Cupressus nootkatensis)*, and Port Orford cedar (*Chamaecyparis lawsoniana*). Special consideration should also be taken to maintain any and all angiosperm species (e.g., Acer, Alnus, Cornus, Populus) natively occurring in the harvest area due to their resistance to laminated root rot. Species conversion silvicultural prescriptions to red alder (*Alnus rubra*) and western redcedar (*Thuja plicata*) are common where laminated root rot is problematic (WSAS 2013). This prescription of species conversion requires on-the-ground forest operator familiarization with and demonstrated expertise in Pacific Northwest native species identification and should be a requirement for harvester contract award. The harvester contract should also specify the removal of harvested forest products from the property to reduce laminated root rot risk. Stumps of harvested trees should be left to decay and provide for nutrient cycling, providing host species boles are removed. Where the removal of harvested trees is not feasible nor economically viable, transfer into streams with salmonid populations will aid in habitat construction and restoration. The pathogen laminated root rot is not likely to be transferred to new stands by the movement of either forest residues or forest products because the fungus is very susceptible to drying and displacement by other organisms (Thies and Sturrock 1995). However, transferring laminated root rot infected wood to uninfected areas poses a (minimal yet acceptable) risk of uninfected susceptible conifer root contact with viable inoculum and persistence of pathogen infection sites, depending on the laminated root rot survival time within any infected timber.

During site visitation and interviews with Union River Watershed Forester, Dave Denis, it was made clear that upon the last effort to remove laminated root rot through harvesting mapped laminated root rot infected timber, replanting of susceptible *Pseudotsuga menziesii* took place across many removal sites. Species replanting took consideration for laminated root rot resistance, and although resistant species *Pinus monticola* and *Thuja plicata* were preferred species, these seedlings were not available for artificial regeneration across the property, and subsequently, the remainder of sites planted *Pseudotsuga menziesii* (Denis 2019). Replanting species *Pseudotsuga menziesii* almost certainly ensured the infestation of laminated root rot into the newly planted seedlings and the continued persistence of laminated root rot on the sites where removal actions were implemented. Laminated root rot expands from a center point outward at low rates, while the center of infection pockets tends to regenerate healthy trees, leaving a poc-marking of forest cover across the landscape (Appendix C). Some sites are exhibiting this infection pattern, but the sites that had *Pseudotsuga menziesii* will likely have an infected core as well as an expanded perimeter area from the harvest site. All *Pseudotsuga menziesii* should, therefore, be removed from sites where they were replanted in an infection site.

Harvest should occur in square blocks to minimize impact areas and reduce the risk of water turbidity to the water supply. Harvesting should take place on sites only where ground and cable logging is a viable option and, therefore, will be restricted to harvest equipment slope restrictions. Where ground or cable logging systems are not a viable option (i.e., where slopes are too steep or where the threat of tree removal poses too great a threat to water turbidity or safety), Option 1 should be considered for implementation. Cable logging on flatter ground may also be desirable to minimize soil disruption. Where slopes are too great for conventional logging systems, and risk to water turbidity levels are high, it would be optional to maintain a stock of viable understory shrub species or laminated root rot resistant species for planting on steep slopes where laminated root rot caused mortality is experienced so slope stability is maintained. Transition to bigleaf maple dominated forest is also an opportunity to encourage forest cover.

Where redcedar is to be planted, harvest blocks should be of a size to permit economically feasible fencing construction around the perimeter of the harvest site, as an alternative to rigid seedling protection tubes (also known as Vexar® tubing). However, block size should be large enough to replicate natural disturbance regimes of the region (i.e., windthrow events or stand-replacing fire events) (Franklin, Johnson, and Johnson 2018). Replication of natural disturbance regimes will enhance public support for operations, allow for productive collaboration compromise space where required, assist with public acceptance, and ensure ecosystem structure and function (Franklin, Johnson, and Johnson 2018). Using a consistent size of harvest blocks will allow for reuse of materials in lateral movement of two sides of the block with only removal and repositioning of one side of the fencing block (Figure 2). This methodology will provide for economic efficiency while providing for effective restriction from grazing herbivores detrimental to successful seedling establishment. To ensure the timely effectiveness of species conversion to prevent forest cover loss from laminated root rot, it would be optimal to implement multiple harvest blocks simultaneously, consistent with this prescription option. In addition, multiple harvest blocks are intended to speed the species conversion process through time, while reducing the time period in which laminated root rot is present on the property.



A perimeter of fencing (red lines) is to be constructed around the harvest site (green) as a part of the regeneration effort to remove herbivory pressures until the seedling establishment and overall height of the seedlings no longer provides a risk of apical meristem consumption by primarily ungulate species residing within the watershed. After herbivory pressures are no longer a threat to the regeneration, fencing Point 1 can be transferred to fencing Point 6, fencing Point 3 can be transferred to fencing Point 8. Fencing leg Point 1 to Point 3 can then be transferred and constructed to create fencing leg Point 6 to Point 8. Fencing leg Point 2 to Point 4 becomes the fencing leg Point 5 to Point 7. Transferring fencing throughout the harvest rotation over the entire watershed will help to minimize costs while eliminating the need for protective tubing for each (western redcedar) seedling planted.

Figure 2: Harvest Block Illustration

Artificial regeneration is recommended under this prescription and treatment should consist of laminated root rot resistant and immune tree species (Appendix B). Maintaining forested cover is an effective means at maintaining forest surface soils, and, therefore, reducing risks to elevated water turbidity levels.

Species recommended for artificial regeneration are western redcedar (*Thuja plicata*), bigleaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), and yellow cedar (*Cupressus nootkatensis*). *Thuja plicata*, *Acer macrophyllum*, *Populus trichocarpa*, and *Cupressus nootkatensis* perform well in mixed stands with some shading from overstory trees. *Alnus rubra* does well on moist sites as a mixed or single species crop. Seedling species planting should also take consideration of matching soil types as detailed in McMurphy 1980. It should be noted that natural regeneration of recalcitrant understory (Option 1) would be expected to uptake lower quantities of water from the watershed when compared with artificial regeneration (Option 2).

Follow-on maintenance of precommercial thinning of naturally regenerated laminated root rot vulnerable species (Appendix B) and competing vegetation must periodically be a part of this treatment application; non-hosts (Appendix B) must remain the only species on the property for at least 50 years to remove the laminated root rot infection.

5.2 Fire Risk

Three options for fire risk reduction at the watershed are outlined below. The option to do nothing also should exist here as a viable option but it should be well understood that doing nothing will not reduce fire risk and will not reduce the total loss of forest cover from a catastrophic fire event. The findings section of this report outlines the possibility of a stand-replacing fire event under a worst-case-scenario model. The recommendation is to devise a combination of the following options.

5.2.1 Option 1

To reduce the risk of stand-replacing fire, forest crown and canopy structure should be reduced to prevent continuity and minimize fuel loads. Thinning tree density down to about 125 trees per acre for 44.4 centimeters DBH Douglas-firs throughout the property will reduce the risk of total forest cover loss during the event of a fire (Hanley and Baumgartner 2005). Risk of torching will still exist due to the understory and regional vegetation type; however, complete forest cover loss will be minimized and will, therefore, help to maintain soil stability. Thinning from above will best suit the reduction in canopy continuity but should be implemented carefully as not to high-grade the forest; that is to not only remove the well-performing trees. Older, more productive trees can provide for a genetic basis for natural regeneration, protection and nutrient support of seedlings (Simard, Jones, and Durall 2003), and habitat through structural heterogeneity and complexity, and support an important piece of ecological function (Franklin, Johnson, and Johnson 2018).

5.2.2 Option 2

Protection of the watershed forested area is imperative for unfiltered water provision. To maintain the highest level of protection from fire, a fire break should be created around the perimeter of the most crucial portion of the drainage basin (Map 3 in Appendix A). The fire break should be down to a depth of mineral soil or bedrock at a width of two tree heights. BehavePlus fire behavior models showed a maximum flame length height of 3.8 meters with some sites containing ladder fuels allowing for torching and/or crown fire. The site index (a measure of site moisture availability) is estimated to be mostly a Douglas-fir (*Pseudotsuga menziesii*) site index class III at which Douglas-fir (*Pseudotsuga menziesii*) are expected to reach heights of 30 meters at age 80 years. Crown fires provide consumptive flames that exceed the height of the dominant cohort of trees on the site, Douglas-fir (*Pseudotsuga menziesii*) in this case. Thus, two tree heights should be sufficient for providing a continuous break in canopy continuity surrounding the most important part of the forested drainage basin (Agee 1998). Fire spotting may be an issue in the event of a crown fire surrounding the fire break; however, the outlined perimeter of protection will also provide firefighters with a location for fighting the flaming front before it reaches proximity to the fire break perimeter, weather and fire conditions permitting.

5.2.3 Option 3

Continual maintenance of watershed access roads should be considered for firefighter access in the event a fire breaks out in the forest. Forest fire is capable of moving through the forest at immense speeds (BehavePlus models for the watershed show rates up to nearly 20 meters per minute, providing a rationale for maintaining large fire breaks as discussed in Option 2) and quick access to unpredictable portions of the watershed may be very time-sensitive in critical moments of firefighting. Road maintenance will also allow for increased policing and patrolling of the property where public access is restricted. Increasing police access will assist in reducing the numbers of human-ignited fires within the watershed. In addition, patrols should be increased during times of high fire threat conditions due to seasonal forest drying.

6. FUTURE RESEARCH

At the introduction of this project, attempts to utilize hyperspatial remote sensing techniques, advanced computer learning, and supervised classification software programs for remote laminated root rot detection were made; however, a much more extensive research time period would be required for meaningful outputs to be rendered. Currently, the most powerful process requires program coding necessary for advanced software product use (Google Earth Engine). Historical mapping would need to be made available for the time period covering the historical laminated root rot locations and ownership of the forested property. Relative levels of root disease severity have been efficiently assessed for inland stands by using l/25,000-scale true color or color infrared aerial photographs (images with pixels of 1-meter resolution or better are recommended for highest accuracy) (Thies and Sturrock 1995). This method is used routinely to characterize the root disease in ecosystem management project analyses in northern Idaho and western Montana (Thies and Sturrock 1995). Problems with such projects have been encountered when aerial surveys have been used to estimate the area affected by root disease in stands of pole-size and larger trees west of the crest of the Cascade Range (Thies and Sturrock 1995). A similar project was conducted to assess the urban forest issues, laminated root rot in particular, in the city of Sammamish. Research followed remote sensing techniques but required a larger sized team and longer duration for research (Patterson and Dyson 2005). Immediate implementation of the above-listed silvicultural prescription options will result in a more resilient ecosystem in the face of forest pathogens, primarily *C. sulphurascens*, and susceptibility to climate change, particularly fire risk, and further research may provide valuable information and insight but may delay the time-sensitive nature of the recommendations in this report.

Further research into the implications of species conversion prescription (Laminated root rot Option 2) application onto the reservoir water chemistry would be a valuable asset for a holistic comprehension of applied methods. Forest soil chemistry changes due to plant species soil nutrient influence may affect hydrological input chemistry of the reservoir. This research would need to take into consideration a collaboration of forest soils expertise in conjunction with hydrological science for analysis outcomes from varied options of species conversion distributions under the prescription option. Geologic or geomorphologic experts may also be of great value for this research to understand chemistry influence of forests as a filtration mechanism. Although the nutrient cycles would not likely exhibit a drastic change from species conversion, if artificial regeneration species selections are concentrated on *Alnus rubra*, increased soil nitrogen levels may influence forest soil acidity levels over time.

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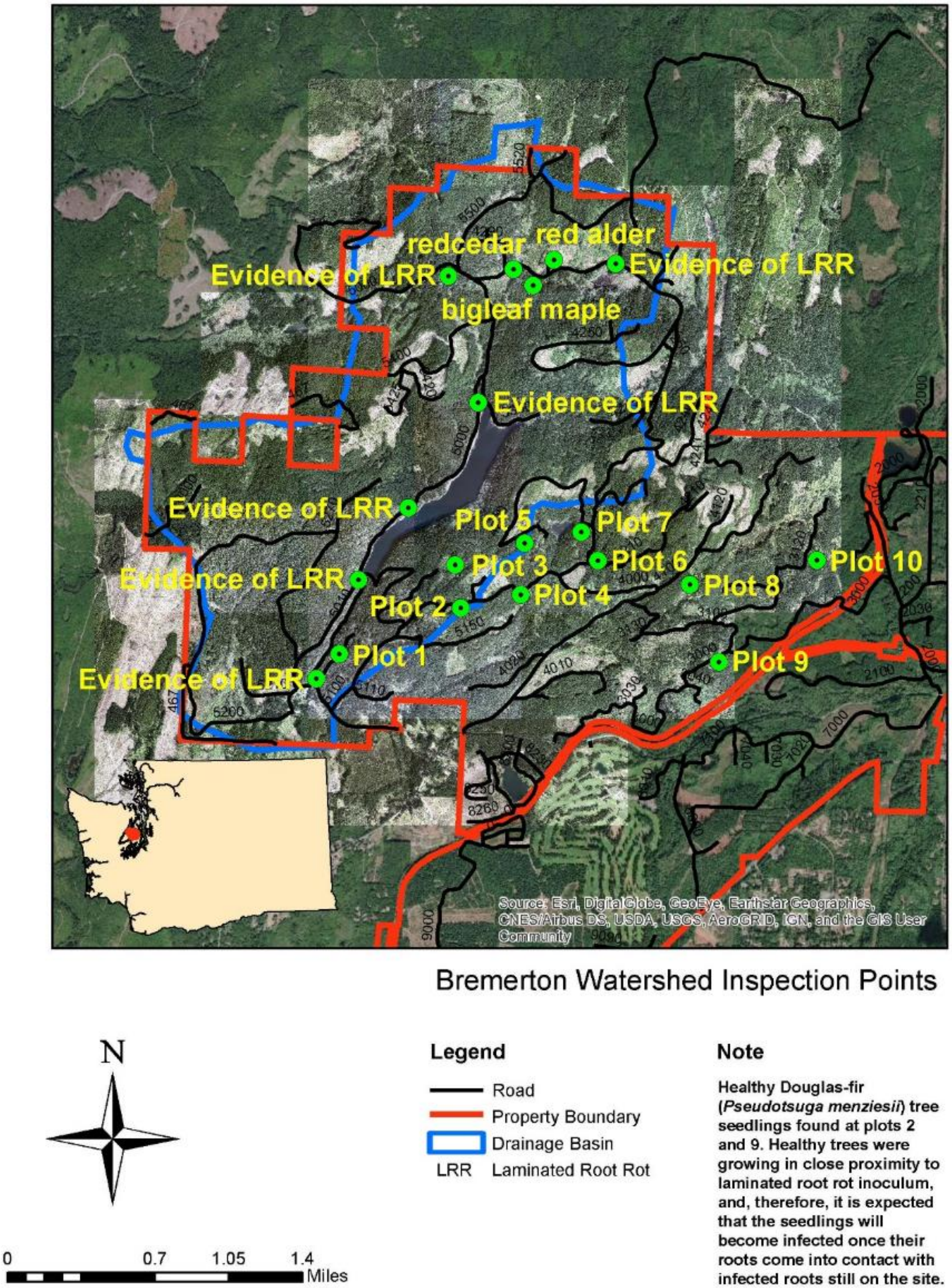
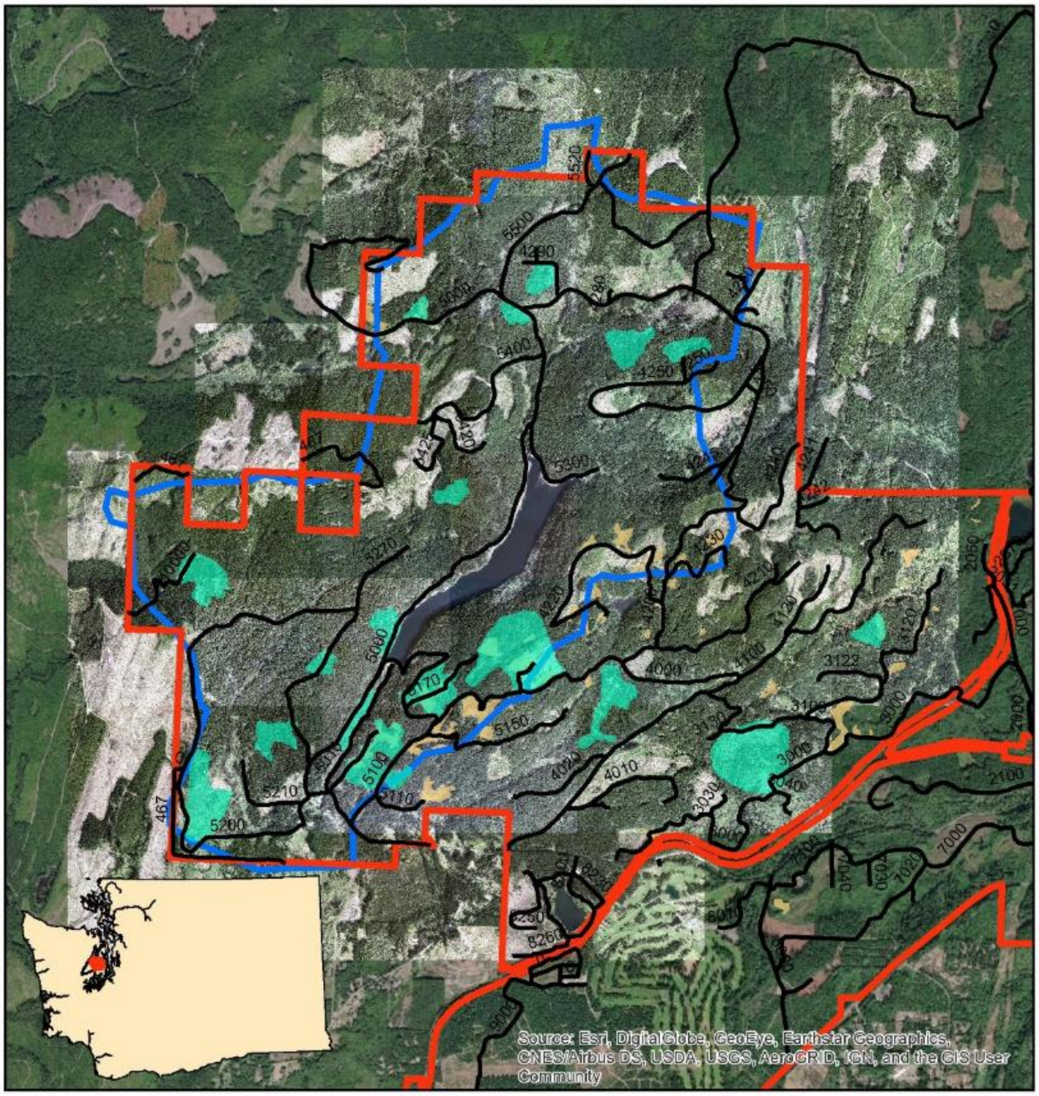
APPENDIX A DIGITAL MAPS OF FOREST HEALTH ATTRIBUTES

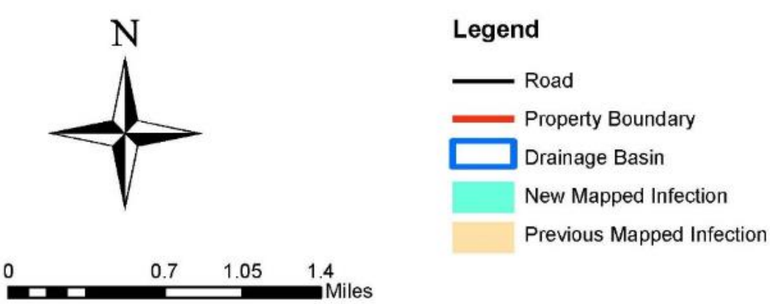
Map 1


redcedar
red alder
Evidence of LRR
Evidence of LRR
bigleaf maple
Evidence of LRR
Evidence of LRR
Plot 5
Plot 7
Plot 3
Plot 6
Plot 10
Evidence of LRR
Plot 8
Plot 2
Plot 4
Plot 1
Plot 9
Evidence of LRR
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Bremerton Watershed Inspection Points
N
0
0.7
1.05
1.4
Miles
Legend
Road
Property Boundary
Drainage Basin
LRR Laminated Root Rot
Note
Healthy Douglas-fir (Pseudotsuga menziesii) tree seedlings found at plots 2 and 9. Healthy trees were growing in close proximity to laminated root rot inoculum, and, therefore, it is expected that the seedlings will become infected once their roots come into contact with infected roots still on the site.

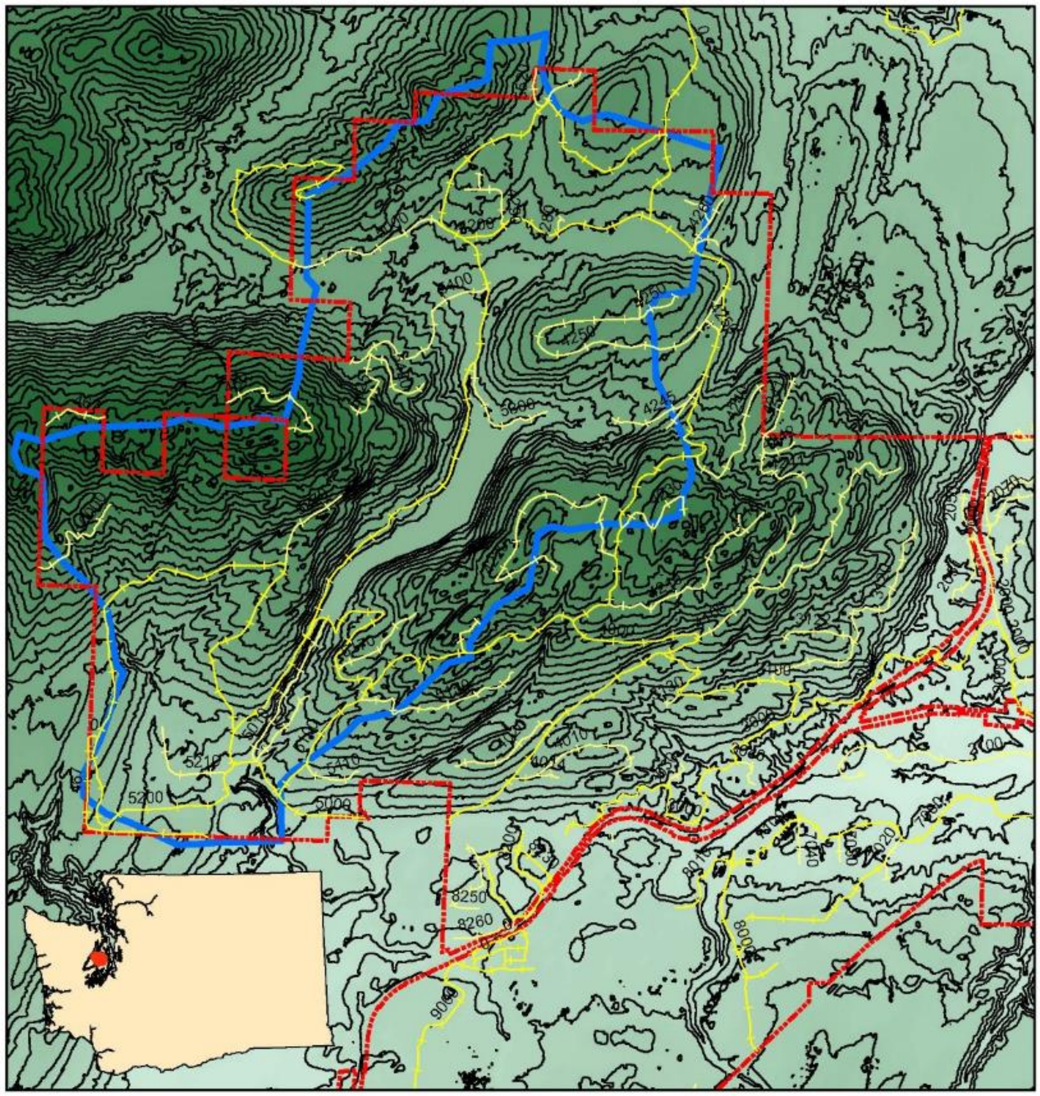
Map 2



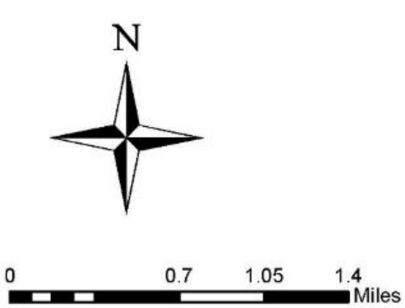
Bremerton Watershed Pathogen Infection Areas



Map 3



Bremerton Watershed High Fire Risk Areas



Legend

- Road
- Property Boundary
- Fire Break Perimeter

Elevation

High : 1764.05

Low : 3.75

Note Creating a fire break is most optimal in the highest elevational area surrounding the critical area. From the contour overlay it becomes clear that this fire break perimeter should be constructed over the drainage basin boundary line, or the fire break perimeter (blue) line, on this map. Special consideration for fire control should be taken to prevent anthropogenic fire by focusing on removal/burning of slash as soon as possible, but advisably within two years after slash piling.

APPENDIX B NATIVE SPECIES SUSCEPTIBLE TO LAMINATED ROOT ROT

Level of susceptibility[a] and species	Scientific name
Highly susceptible:	
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Pacific silver fir	*Abies amabilis* Dougl. ex Forbes
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.
Intermediately susceptible:	
California red fir	*Abies magnifica* A. Murr.
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Giant sequoia	*Sequoiadendron giganteum* (Lindl.) Buchholz
Noble fir	*Abies procera* Rehd.
Pacific yew	*Taxus brevifolia Nutt.*
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Western hemlock	Tsuga heterophylla (Raf.) Sarg.
Western larch	*Larix occidentalis* Nutt.
Tolerant:	
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Sugar pine	*Pinus lambertiana* Dougl.
Western white pine	*Pinus monticola* Dougl. ex D. Don
Resistant:	
Alaska-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach
Incense-cedar	*Libocedrus decurrens* Torr.
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Redwood	*Sequoia sempervirens* (D. Don) Endl.
Western redcedar	*Thuja plicata* Donn ex D. Don
Immune:	
Hardwoods[b]-	
Bigleaf maple	*Acer macrophyllum* Pursh.
Mallow ninebark	*Physocarpus malvaceus* (Greene) Kuntze
Ocean-spray	*Holodiscus discolor* (Pursh) Maxim.
Red alder	*Alnus rubra* Bong.
Rocky Mountain maple	*Acer* glabrum Torr.
Vine maple	*Acer circinatum* Pursh

[a]Levels of susceptibility: high-readily infected and readily killed; intermediate-readily infected, usually not killed, often develops butt decay; tolerantinfrequently infected unless growing in association with the most susceptible species, rarely killed; and resistant-rarely infected, almost never killed.

[b]All hardwoods are immune.

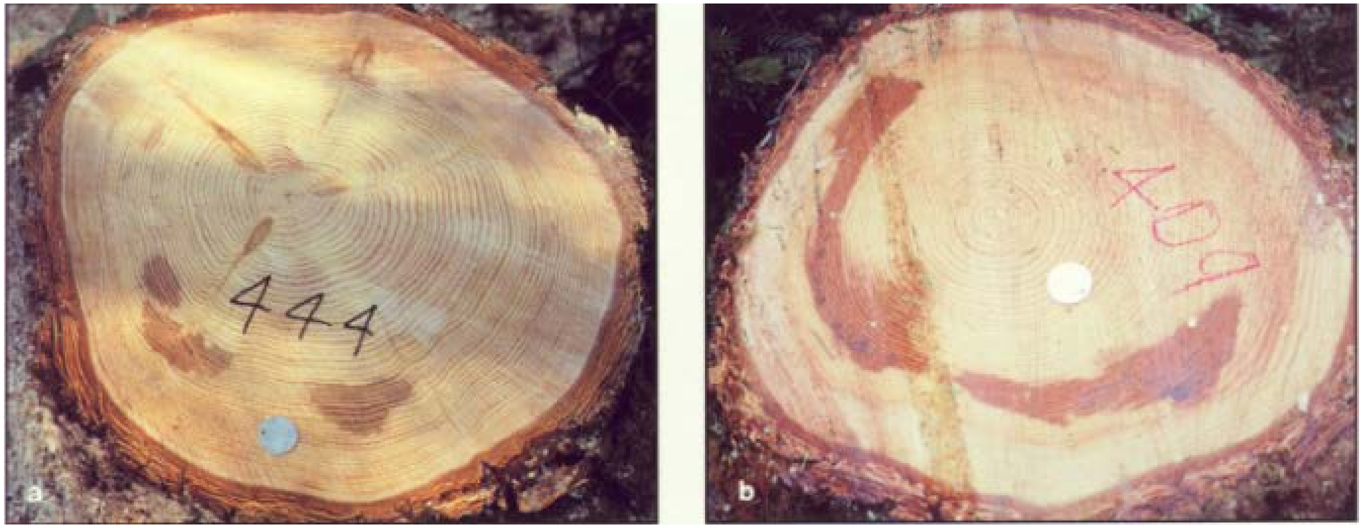
Sources: Adapted from Filip and Schmitt 1979, Hadfield 1985, Nelson and Sturrock 1993, Wallis 1976.

Source: Thies and Sturrock 1995

The table above includes the susceptibility of western North American tree species to laminated root rot. Species conversion treatment advises using low-susceptibility (tolerant/resistant) or immune species listed in the table.

APPENDIX C PHOTOGRAPHS

Photograph 1



Textbook example: Characteristic decay (stain) caused by *C. sulphurascens* as seen on fresh Douglas-fir stump tops. The stain is typically reddish brown to chocolate brown. Source: Thies and Sturrock 1995

Site example: recently harvested (within 45 days of removal) stump. View of a new fresh cut near the root collar where *C. sulphurascens* evidence was observed. Characteristic stain not present within stump wood. Source: Semler 2019

Photograph 2

Textbook example: Uprooted Douglas-firs with root wads characteristic of laminated root rot infection. Decaying roots have broken close to the root collar leaving only stubs. Source: Thies and Sturrock 1995

Site example: Root ball tip up mound indicative of laminated root rot infection. Source: Semler 2019

Photograph 3

Textbook example: (left) Typical laminated decay caused by *C. sulphurascens*. This piece of root delaminated at the spring wood into sheets, each the thickness of an annual ring. Source: Thies and Sturrock 1995

Site example: (right) Breakage showing laminated layers indicating laminated root rot. Source: Semler 2019

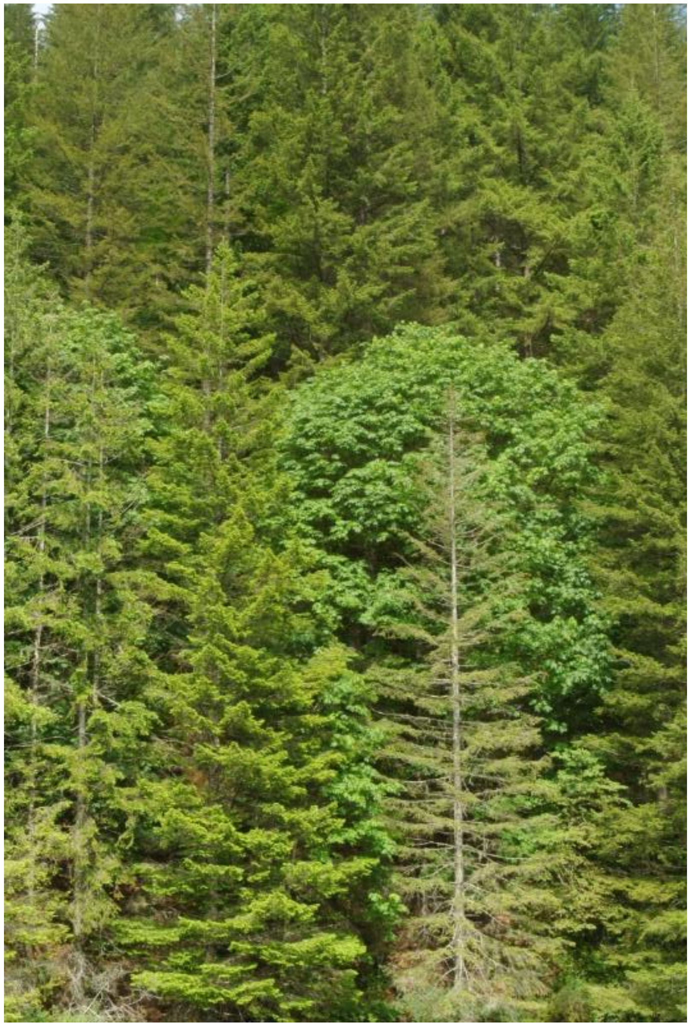
Photograph 4

The stump from a tree that was killed by laminated root rot. This example shows how close the inoculum is to growing trees – ensuring the continuance of laminated root rot in the new generation of living trees. Source: Semler 2019

Photograph 5

Laminated layers after breakage (left) with broken infected *C. sulphurascens* infected wood (right). Source: Semler 2019

Photograph 6



Textbook example (left): Douglas-fir crown infected by *C. sulphurascens*. Note the rounded top, bushy branch ends, and thinning foliage of this tree, which contrast with healthy firs in the immediate background. Source: WSAS 2013

Site example (right): Contrasting sick and healthy trees within a rot pocket. Viewed from standing on Casad Dam. To the right is the reservoir, to the left is release stream. In the foreground; *C. sulphurascens* infected tree at the right, healthy tree at left. Source: Semler 2019

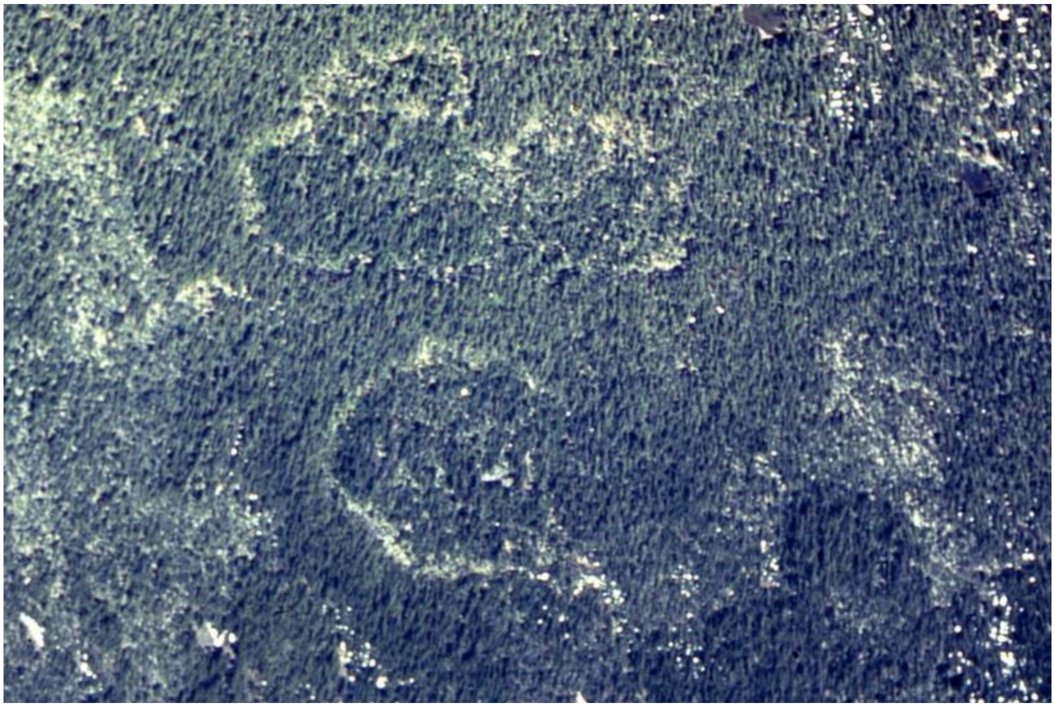
Photograph 7

Rot pocket viewed from standing on Casad Dam. To the right is the reservoir, to the left is release stream. Source: Semler 2019

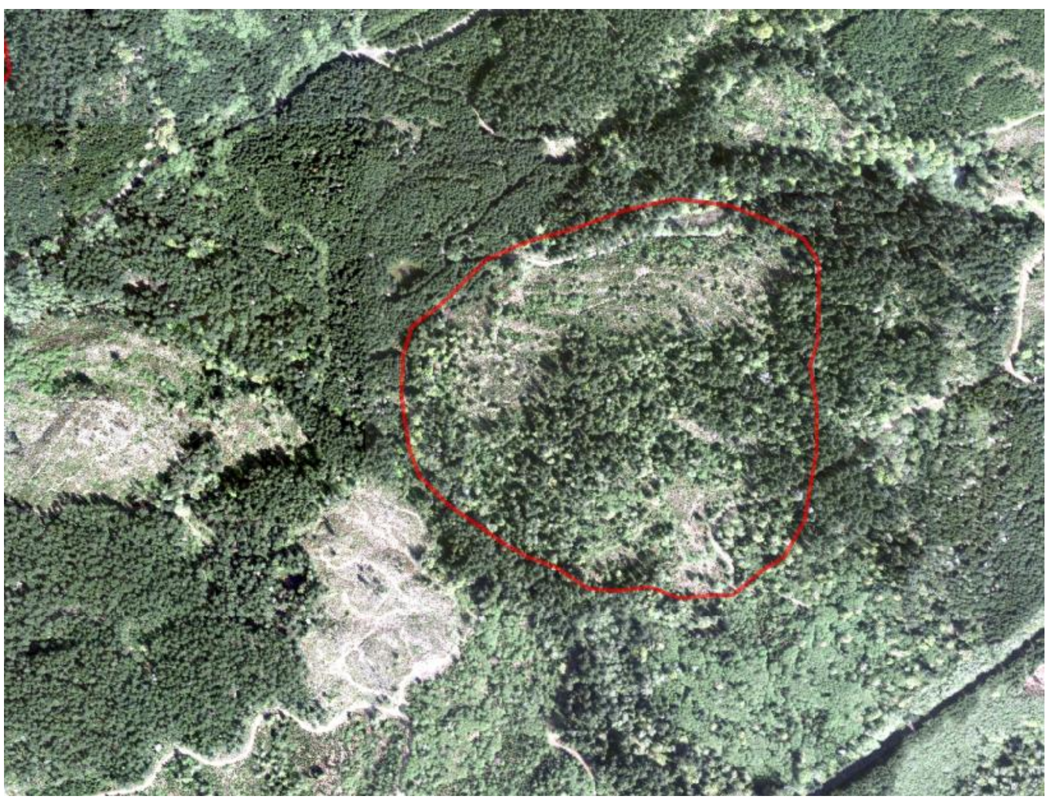
Photograph 8

Area of infection pocket shows breakage of multiple trees and forest gap from dying trees. Source: Semler 2019

Photograph 9



Textbook example: Laminated root rot (*C. sulphurascens*) pockets. Waldo Lake, Oregon. Source: USDA 2007



Site example: Outlined image of landscape-scale laminated root rot in comparison to a confirmed case of laminated root rot above. Source: City 2015

Photograph 10

Textbook example: (left) Light-colored ectotrophic mycelia often cover the surface of an infected root to form a sheath. This mycelial sheath can be seen by carefully brushing soil away from an infected root. (right) A sheath of ectotrophic mycelia usually covers the roots and a belowground portion of the stem of a diseased seedling. Source: Thies and Sturrock 1995

Site example: Ectotrophic mycelia mat forming on Douglas-fir (*Pseudotsuga menziesii*) root collar bark. Source: Semler 2019

Photograph 11

Showing stand structure with surface to crown continuity. Shows where tree crowns will burn in the event of a wildfire. Source: Semler 2019

Photograph 12

Unknown black substance; possibly a canker fungus. Source: Semler 2019

APPENDIX D FCCS SURFACE FIRE BEHAVIOR REPORT

FCCS 3.0 Surface Fire Behavior Report

Report date: May 26, 2019
Unit Name: Bremerton1
EV Name: FCCS Benchmark Inputs

Filename	ID	ROS ft/min	FL ft	RI total	RI shrub	RI herb	RI wood	RI llm	Crosswalk	% ROS	% FL	Crosswalk	% ROS	% FL
				|-------------		BTU/ft2/min		-------------|	|-----------	Fuel Model 13	------------|	|-----------	Fuel Model 40	------------|
FB_0009_FCCSu01	9u1	11.9	7.4	6366	2919	564	2236	646	12	102	100	SB3	58	93
FB_0018_FCCSu01	18u1	10.1	4.2	2948	1301	834	389	424	10	135	89	TU4	112	85
FB_0305_LFu01	305u1	4.1	1.4	906	197	143	5	560	8	247	138	TL5	120	72

The surface fire behavior report includes predicted surface fire rate of spread (ROS), flame length (FL), and total reaction intensity (RI) and reaction intensity by surface fuel stratum including shrubs, herb, wood, and litter-lichen-moss (LLM).

Parameters: Wind (4mph), Slope (0%), 1hrFM (6%), 10hrFM (7%), 100hrFM (8%), ShrubFM (90%), HerbFM (60%).

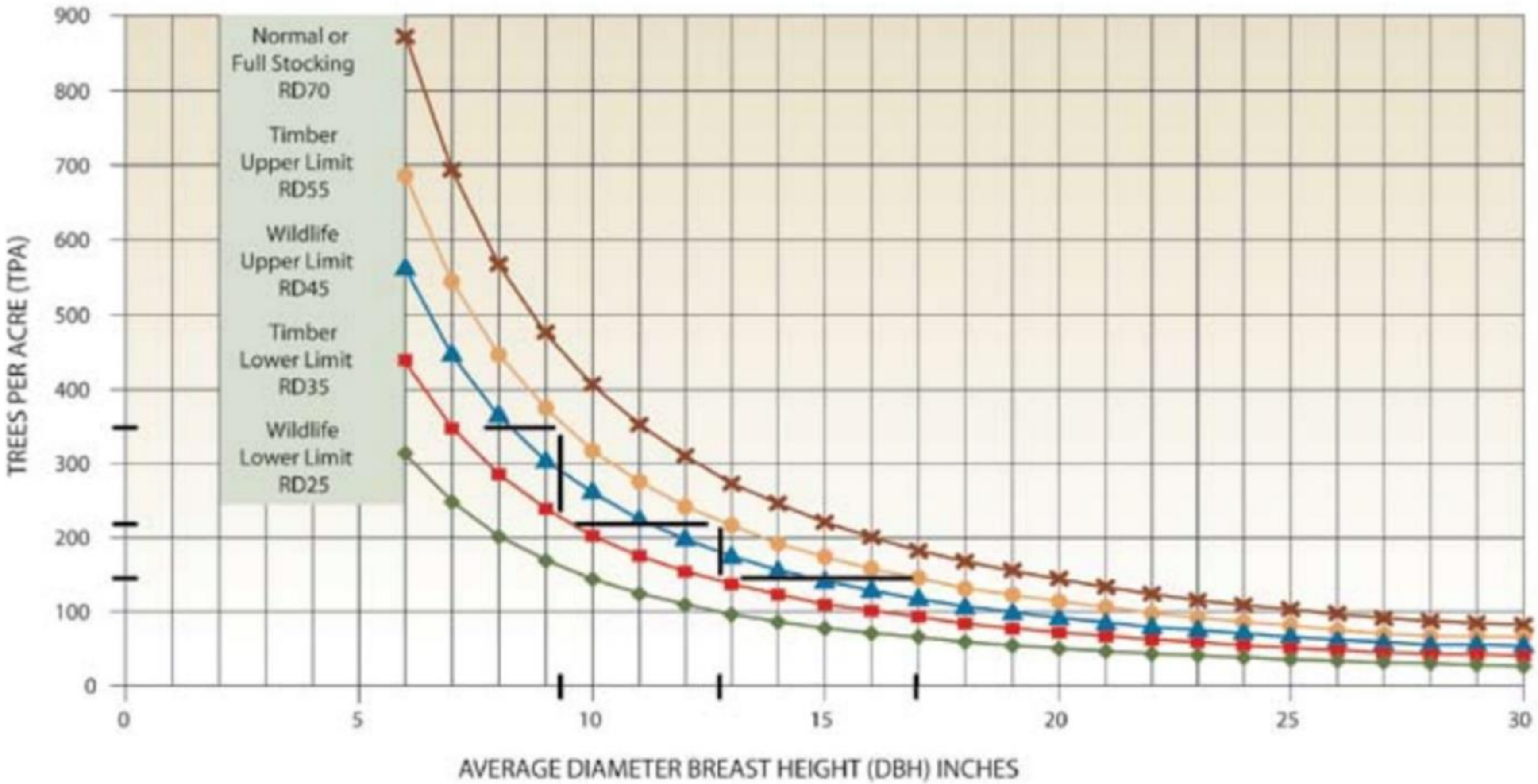
Filenames:

FB_0009_FCCSu01: Douglas-fir (*Pseudotsuga menziesii*) stands with no ladder fuels. Model inputs matched field sites for this forest type.

FB_0018_FCCSu01: Douglas-fir – western hemlock (*Pseudotsuga menziesii – Tsuga heterophylla*) stand with ladder fuels. Model inputs matched field sites for this forest type.

FB_0305_LFu01: Red alder (*Alnus rubra*) stand. Model inputs matched field sites for this forest type.

APPENDIX E STAND DENSITY DIAGRAM

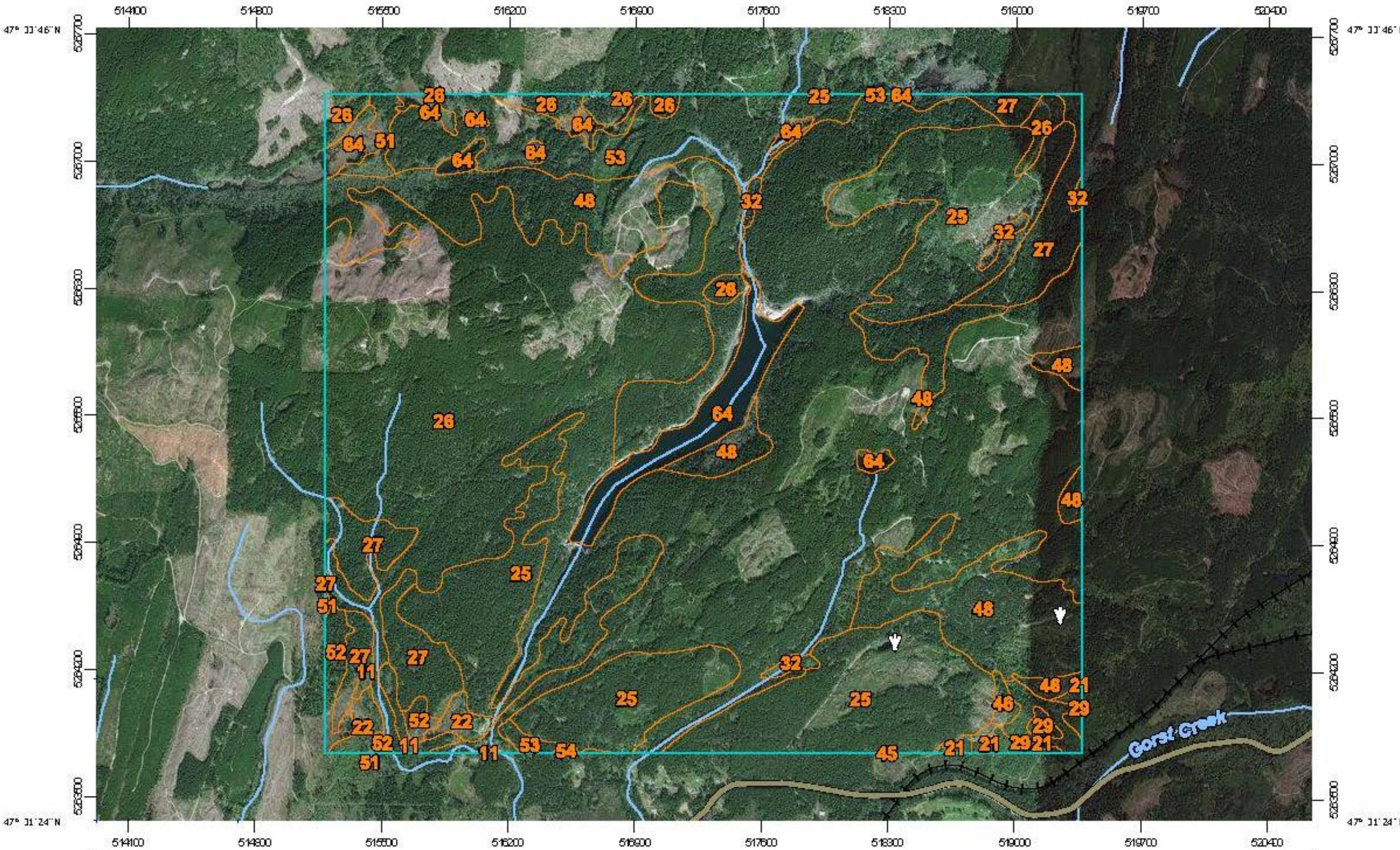


Stand density diagram for westside Douglas-fir, showing general guidelines for normal or full stocking, at a relative density of 70 (RD70); the upper timber limit, RD55; the upper wildlife limit, RD45; and the lower wildlife limit, RD25. Source: Hanley and Baumgartner 2005

APPENDIX F NRCS WEB SOIL SURVEY

Soil Map—Kitsap County Area, Washington

122° 48' 54" W 122° 41' 32" W



122° 48' 54" W 122° 41' 32" W

Map Scale: 1:30,700 if printed on A landscape (11" x 8.5") sheet.

N

0 450 900 1800 2700 Meters

0 1000 2000 4000 6000 Feet

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 10N WGS84

Soil Map—Kitsap County Area, Washington

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features

- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Kitsap County Area, Washington
Survey Area Data: Version 14, Sep 10, 2018

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Mar 29, 2016—Sep 27, 2016

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
11	Grove very gravelly sandy loam, 0 to 3 percent slopes	15.7	0.4%
21	Indianola-Kitsap complex, 45 to 70 percent slopes	25.5	0.7%
22	Kapowsin gravelly ashy loam, 0 to 6 percent slopes	26.9	0.7%
25	Kilchis very gravelly sandy loam, 15 to 30 percent slopes	684.8	18.2%
26	Kilchis very gravelly sandy loam, 30 to 70 percent slopes	1,934.0	51.3%
27	Kilchis-Shelton complex, 30 to 50 percent slopes	170.1	4.5%
29	Kitsap silt loam, 8 to 15 percent slopes	18.2	0.5%
32	McKenna gravelly loam	16.8	0.4%
45	Ragnar fine sandy loam, 6 to 15 percent slopes	0.0	0.0%
46	Ragnar fine sandy loam, 15 to 30 percent slopes	15.0	0.4%
48	Schneider very gravelly loam, 45 to 70 percent slopes	482.5	12.8%
51	Shelton very gravelly sandy loam, 0 to 6 percent slopes	15.6	0.4%
52	Shelton very gravelly sandy loam, 6 to 15 percent slopes	28.6	0.8%
53	Shelton very gravelly sandy loam, 15 to 30 percent slopes	204.5	5.4%
54	Shelton very gravelly sandy loam, 30 to 45 percent slopes	2.0	0.1%
64	Water	128.5	3.4%
Totals for Area of Interest		**3,768.5**	**100.0%**