Managing Root Disease in British Columbia

BRITISH COLUMBIA
Ministry of
Forests, Lands, Natural
Resource Operations
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Cover photos

Top: Young Douglas-fir stand in the Okanagan infected with Armillaria root disease

Middle row (L-R): black staining in Douglas-fir sapwood caused by black stain root disease; underside of Douglas-fir bark showing Armillaria fans; advanced decay caused by laminated root disease

Bottom row (L-R): fruiting body of annosus root disease; Armillaria mushrooms with recently released spores; Tomentosus fruiting bodies

Purpose

This document provides a comprehensive description of the objectives and scope of root disease management in British Columbia (BC). It is not designed as a field guide or diagnostic tool, but rather is intended to help forest professionals and practitioners navigate the challenges of operating in areas impacted by root disease by providing science-based survey and treatment options that are applied consistently across the province. Using this information to guide site-specific treatments is key to maintaining long-term site productivity and enhancing the economic value of BC's timber supply. Forest professionals are encouraged to follow the best management practices and associated strategies in this document to achieve proper site preparation and regeneration to support sustainable reforestation, and ecosystem productivity and integrity. For more information on insects, diseases, and forest health in BC, please refer to the Forest Health website: https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health?keyword=forest&keyword=health.

A discussion of climatic impacts on root disease is beyond the scope of this document. However, emerging science has identified that environmental stress does contribute to the vulnerability of host tree species, which may lead to an increase in root disease. For example, an increase in the frequency and intensity of unusually hot and dry summers amplifies the impacts of root disease (Kliejunas et al., 2009). Sturrock et al. (2011) provides insight into some of the potential interactions between climate change and forest diseases. For information on climate change and its relevance to forest management in BC, please refer to the ministry's Climate Change website: https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/natural-resources-climate-change.

Dead and symptomatic trees in laminated center overlooking Middle Lake

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Contact List: BC Forest Pathologists

Provincial Contact		
Region/Division	**Location**	**Phone number**
Resource Practices Branch	Victoria	1 (250) 387-1946

Regional Contacts		
Region/Division	**Location**	**Phone number**
Kootenay/Boundary Region	Nelson	1 (250) 354-6710
Omineca & Northeast Regions	Prince George	1 (250) 561-3479
Skeena Region	Smithers	1 (250) 847-6300
Thompson/Okanagan & Cariboo Regions	Williams Lake	1 (250) 398-4345
West & South Coast Regions	Nanaimo	1 (250) 751-7001

Root rot centers (lighter areas) on hillside near Salmon Arm

Introduction: Root Disease and Stand Dynamics

Root disease fungi are natural components of forest ecosystems. They inhabit diverse environments and can live and grow on sites for a very long time. For example, a single clone of Armillaria root disease (*Armillaria ostoyae*) is estimated to occupy an area close to 1000 ha and be between 1900-8700 years old (Ferguson et al., 2003). From a biodiversity perspective, the presence of root disease on a site can be beneficial. Root disease fungi cause decay and mortality in trees of all sizes, which leads to more structural diversity (Hansen and Goheen, 2000; Newberry et al., 2007). The presence and distribution of root disease on a landscape can effectively advance forest succession by modifying a relatively dense second-growth stand, with little understory vegetation and minimal species diversity, into a more open, structurally and biologically diverse condition. The creation of openings in the forest canopy by root disease is also beneficial for wildlife and other non-timber forest resources.

Douglas-fir stump with bark removed to show Armillaria fans

Timber harvesting can favour the spread of root disease. The creation of stumps eliminates the natural removal of large roots that occurs when trees with root disease weakened roots fall over. Armillaria root disease, *Armillaria ostoyae*, can spread rapidly through the roots of recently cut infected stumps. From these stumps, Armillaria can infect nearby healthy Douglas-fir trees (Cruikshank et al., 1997). Tomentosus root disease, *Onnia tometosa*, has been shown to spread outward from the heartwood of stump roots to the outer sapwood, increasing the chances of root to root spread (Lewis and Hansen, 1991). In addition, harvesting and thinning creates large amounts of exposed stump surfaces, increasing the risk of spore infection by annonsus root disease (*Heterobasidion* spp.) (Morrison and Johnson, 1999). Harvesting can also cause a significant increase in the abundance of insect vectors of black stain root disease (*Ophiostoma* spp.) (Witcosky et al., 1986).

Rapid regeneration using susceptible hosts on infected sites following harvest increases the probability of future mortality because seedlings of susceptible tree species provide a new source of tissue and support the spread of infection (Morrison and Mallett, 1996). Depending on the tree species selected by the practitioner at the time of reforestation, root disease incidence can increase on a site if a higher proportion and/or density of susceptible tree species is chosen compared to the former stand (Woods, 2003). In some areas, forest management practices have increased the incidence and severity of the root diseases to levels above those that are acceptable for sustainable forestry (Sturrock, 2000). For all these reasons and more, it is imperative that appropriate surveys and treatments are used to minimize the spread of root disease and mitigate losses in managed stands.

Complete eradication of root disease at both the stand and landscape level is neither practical nor desirable from an ecological perspective. However, practicing good root disease management is essential to prevent **root disease from increasing** in managed stands over time (i.e., if unmanaged, root disease has the potential to impact the future productivity and value of BC's timber resources).

Inoculum potential

The risk that root diseases pose to future stand productivity depends upon the 'inoculum potential' which is defined as the energy available to the fungus to infect new hosts over time (Tainter and Baker, 1996).

Inoculum potential naturally declines over time as the infected stump is consumed or invaded by other fungi and insects. Other factors that influence the decline of inoculum potential are tree species, time left undisturbed, and the physical environment. Inoculum potential can be reduced more quickly by removing the stump or opening it to expose the pathogen to competitors and drying conditions.

Advanced decay from laminated root disease in a western hemlock stump

Major Root Diseases in British Columbia

The most significant root disease fungi in BC are listed in Table 1. Table 2 lists the relative susceptibility of the host tree species for each of the major root diseases. The signs and symptoms of each root disease can be found in the Field Guide to Forest Damage in British Columbia (Burleigh et al., 2014), and other supporting information is provided in Appendix 1. Generalized distribution maps for each root disease are provided in Appendix 2. **It is important to combine this information with local knowledge and site-specific information before plans are finalized**.

Table 1: Major root disease fungi in British Columbia.

Common Name	Pest Species Code	Scientific Name	Also Known As	Principle Range
Annosus root disease	DRN	*Heterobasidion irregulare*	*H. annosum, P-type*	Okanagan Valley*
		Heterobasidion occidentale	*H. annosum, S-type*	Throughout BC
Armillaria root disease	DRA	*Armillaria ostoyae*	*Armillaria solidipes*	Throughout southern and coastal BC
Black stain root disease	DRB	*Ophiostoma wageneri*	*Leptographium wageneri var. ponderosum*	Southern Interior
		Ophiostoma wageneri	*Leptographium wageneri var. pseudotsugae*	Southern BC
Laminated root disease**	DRL	*Phellinus sulphurascens*	*Inonotus sulphurascens*	Throughout southern and coastal BC
Tomentosus root disease	DRT	*Onnia tomentosa*	*Inonotus tomentosus*	Throughout northern BC and higher elevations in the Southern Interior

* The P-type of annosus root disease (*Heterobasidion irregulare*) has only been recently reported in BC.

** This guide only covers the Douglas-fir strain of laminated root disease (*Phellinus sulphurascens*). The cedar strain, *Phellinus weirii*, is not actively managed because it behaves more like a butt rot. It is considered a wood-decay fungus rather than a pathogen of cedar.

Table 2: The relative susceptibility of host tree species to the major root diseases in British Columbia.

Common Name	Relative Susceptibility					Reference
	Highly Susceptible	Intermediately Susceptible	Tolerant[1]	Resistant[1]	Immune	
Annosus root disease*	western hemlock	Douglas-fir				Morrison 1979; Schmitt et al., 2000
	amabilis fir	western redcedar				
	subalpine fir	Sitka spruce				
Armillaria root disease	subalpine fir	lodgepole pine	mature larch	hardwoods	none	Cleary et al., 2008; Morrison et al., 1992
	Douglas-fir	western white pine	western redcedar			
	spruce	western hemlock				
		ponderosa pine				
Black stain root disease**	lodgepole pine					Hunt & Morrison 1995
	ponderosa pine					
	Douglas-fir	western hemlock				
Laminated root disease	Douglas-fir	western hemlock	pines	western redcedar	hardwood	Thies & Sturrock 1995; Sturrock et al., 2006; Cleary et al., 2011
	grand fir	western larch		yellow cedar		
	amabilis fir	subalpine fir				
	mtn. hemlock	Sitka spruce				
		Engelmann spruce				
Tomentosus root disease	white spruce	lodgepole pine	subalpine fir	western redcedar	hardwood	Reich et al., 2013
	Engelmann spruce	Douglas-fir	western white pine	western hemlock		
	black spruce					

[1] The list reflects current available information and local expert knowledge; there are disagreements in the literature about the categories of tolerant vs. resistant. These categories should be used as general guidance.

* Only the relative susceptibility of hosts to the S-type of annosus root disease (*Heterobasidion occidentale*) is shown because the P-type (*Heterobasidion irregulare*) has only recently been reported in BC.

** Black stain root disease refers to both the pine strain and the Douglas-fir strain.

Impacts of Root Disease

Root disease is responsible for major timber loss due to mortality, growth loss, and butt cull (Whitney, 1988). If left untreated in managed stands, cumulative mortality from Armillaria root disease can reach 15-20% at 20 years of age (Morrison and Pellow, 1994). Root disease fungi further compromise the ability to meet timber management goals by causing significant growth loss often in the absence of readily observable symptoms (Cruickshank, 2000; Morrison et al., 2000). For example, Thies and Westlind (2005) reported a 25% mean reduction in wood volume in 25-year-old Douglas-fir stands. Calculations of volume loss in the butt log of western hemlock due to decay have shown an annual increase of gross volume loss of about 1.0-1.5% (Wallis and Morrison, 1975). Butt cull from tomentosus can account for up to a 30% loss of net merchantable volume in severely infected spruce trees (Lewis, 1997).

Combined losses to timber volume and value caused by the major root diseases in BC are estimated at over 3.8 million m^3 annually (Morrison et al., 1992), with Armillaria root disease being responsible for 2-3 million m^3 alone (Morrison and Mallett, 1996).

The proactive steps outlined in this root disease management document form part of a long-term strategy to help maintain the productivity of forests by reducing the impacts of root disease.

Dead and symptomatic trees killed by laminated root rot

Assessing Root Disease Hazard

The potential threat posed by root disease varies across the province (see Appendix 2 for root disease distribution maps). The decision to apply a root disease treatment should be based on an assessment of the future risk from root disease and the overall management objectives for the site.

Reviewing which pathogens may be present is the **first step** when determining the site-specific root disease hazard and the potential risk to timber management. Regional hazard tables arranged by Biogeoclimatic Ecosystem Classification (BEC) variants that may contain areas of high hazard are provided in Appendix 3. This information is to guide forest professionals and practitioners but must not replace ground surveys. These hazard ratings should be considered when developing Forest Stewardship Plans and Site Plans, and must be included in TSA/District Forest Health Strategies.

The **second step** is to acquire detailed site-level information from a walkthrough or more detailed ground survey. This detailed, site-specific information is required to estimate risk, which will support the decision of whether to treat or not, and if treatment is required, which treatment(s) are most suitable.

It is important to recognize both the potential and limitations of technology in regard to locating, identifying and mapping stands infected by root disease. Tablets are a useful tool for traversing root disease centers and have made root disease mapping simpler in mature stands; however, technology is not a substitute for ground surveys by skilled surveyors.

Douglas-fir with rounded crown, sparse foliage, and stress cones caused by root disease

Site Surveys for Root Disease

Surveying for root disease requires skilled surveyors that pay close attention to host tree species and are proficient at recognizing the signs and symptoms of the pathogens. The survey must sufficiently cover the site and use systematic and quantifiable methods of recording the intensity and location of the damage to make well-informed decisions about treatment type and intensity.

There are four recommended methods for surveying root disease.

1. Preliminary walkthrough

The preliminary walkthrough provides an early opportunity to confirm disease occurrences, assess the risk posed to management objectives, stratify the areas by root disease, and estimate the presence of other damaging agents. The walkthrough should be conducted over the entire site and provide enough information to categorize the risk that root disease poses to stand management objectives. However, further surveys may be needed to accurately define treatment areas. The result of the preliminary walkthrough will support future actions (i.e., conducting a detailed survey to determine whether a treatment threshold has been met) and can be combined with aerial photos, LiDAR or helicopter flights to help identify and delineate root disease centers from stand/landscape features (such as species composition and dead trees) and openings data. However, some type of ground survey is still required to confirm root disease signs on the ground and determine the species of root disease. To find out if root disease shapefiles are available for your area, contact your Regional Pathologist.

A walkthrough survey may not provide enough information to properly delineate root disease treatment units. The following situations indicate that you must use one of the other three survey methods outlined below to collect adequate information:

1) The distribution could not be accurately determined by the preliminary walkthrough;
2) Small, dispersed root disease centers are found in the preliminary walkthrough; or
3) Multiple species of root disease are found and the treatment boundaries need to be refined.

2. Pre-harvest sketch mapping survey

An area-based sketch map survey can delineate the approximate areas where root disease exists to stratify areas for treatment. An example of a sketch map is provided in Appendix 4. This method is ideal in areas with well-defined root disease centers. Sketch mapping is very difficult or impossible in situations where there is scattered mortality due to root disease interspersed with asymptomatic trees.

The entire area is mapped at a scale of no more than 1:5000 by systematically walking the site using a tablet or walking along parallel strip lines spaced close enough that all the area between lines is visible (usually 30-50 m apart in mature stands and less in denser stands). All dead standing and infected downed trees, and all symptomatic individual trees, groups of trees, and infection center openings, are sketched to an accuracy of ±5 m and the causal root disease fungus is identified.

Following the pre-harvest sketch mapping, treatment buffers can be added around each infection center (10 m for pre-harvest stands). These buffers delineate the extra area likely occupied by the infected root systems. Care should be taken not to stratify treatment areas too finely as it is better to increase a treatment area rather than make it too small.

3. Variable-width transect survey

The tree-based, variable-width transect survey is suitable for estimating disease incidence in almost all stand types and for all root diseases. Depending upon the transect interval, this method also provides an accurate estimate of disease location. This survey method is ideal for situations where mortality and symptomatic trees are scattered throughout the stand or where there is a mixture of tree species that vary in their susceptibility to root disease (Table 2).

Variable-width transects are designed to account for variation in stand density while still capturing sufficient trees to provide a valid sample. A rule-of-thumb for selecting the transect width based on stand density is: <1000 sph - 5 m, 1000-2000 sph - 3 m, and >2000 sph - 2.5 m. Transect spacing also influences the quantity of trees assessed. For stands up to 15 ha, a transect interval of 50 m is recommended. For larger areas, a wider interval may be used, but it should not exceed a maximum of 100 m.

Field Procedure

1. Create a large scale map of the stand (e.g., 1:5000) and lay out parallel transect lines over the entire area prior to conducting the field portion of the survey. The point-of-commencement (POC) should be placed 50 m from the edge of the stand and transect lines should not come closer than 10 m to any stand boundary.
2. Record the transect lines and notes on a suitable tracking sheet. Transect lines should be flagged so the lines can be easily relocated for inspection. Flag the beginning of each line with a ribbon marked with the date, survey title (e.g., root disease survey), and bearing of the line.

3. Along each transect line record:
    a. Location of susceptible tree species and their dbh (if >1.3 m tall or other size limit);
    b. Location of dead or infected trees (>1.3 m tall);
    c. Status of tree (i.e., healthy, standing-infected, standing-dead, windthrown, etc.); and
    d. Presence and extent of infection centers (optional).

    Note: Trees down due to windthrow should be noted only if root disease can be identified as the predisposing factor (causal agent).
4. Total the number of infected trees and the total number of examined trees and determine the disease incidence of each stratum.
5. Use incidence and distribution information to decide on treatment, if required.

4. Post-harvest stump top survey

Stump top surveys are used to accurately confirm disease incidence after harvest and to delineate treatment strata based on observable signs and symptoms when clearly visible on freshly cut stumps. The sooner the survey is conducted, the better because staining that precedes some types of root disease-mediated decay fades over time. During a systematic grid search of the site, infected stumps are clearly marked with log-marking paint either for stump removal or stump avoidance. This method works best in situations where indicators of decay like stained, delaminated and pitted wood can be readily assessed from freshly cut stump surfaces.

Stain (arrow) caused by laminated root disease seen in log butts at a landing

Treatment Options for Reducing Risk of Root Disease

The best opportunity to address root disease and minimize future losses is during the planning process, prior to harvesting, when the site and resources are assessed and the need for appropriate treatments is determined. The disease-specific treatments that are currently recommended in BC are presented in Table 3. Most recommended treatments are implemented during or immediately following harvest.

The primary reference for species selection in BC is the *Reference Guide for Forest Development Stocking Standards*. This guide, as well as the Tree Species Selection Tool and information on seed planning and use, can be found at: https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/silviculture/stocking-standards.

Recommended Treatments

Table 3: Recommended treatments for the major root diseases in British Columbia.

Tactic	Disease[1]	Comments
Regenerating with less susceptible species	DRA, DRB, DRL, DRN, DRT	Most common and widely used form of treatment. Ecologically appropriate species must be chosen while keeping in mind that the selection of species must consider relative susceptibility.
Stump removal	DRA, DRL, DRN, DRT	A proven effective treatment for controlling disease and improving tree growth (through soil mixing), but not appropriate for all sites.
Pushover harvesting	DRA, DRL, DRN, DRT	Not widely practiced though can be effective. Equipment may need to be modified to address operator safety concerns.
Facilitating hardwood regeneration	DRA, DRL, DRT	Hardwoods slow the spread of root disease, but also compete with conifers and can compromise timber management goals. It is important to recognize that no hardwood species are absolutely immune to Armillaria root disease.
Biological control	DRN	In Canada, *Phlebiopsis gigantea* is registered for use to control *Heterobasidion irregulare*. Regulatory approval is required from Health Canada to use *Phlebiopsis gigantea* to control *Heterobasidion occidentale*. Other biological control combinations are not recommended – see Table 4.
Stump avoidance	DRT	Not planting susceptible species within 5m of an infected stump can substantially reduce the probability of infection provided there are enough suitable planting sites that are not within 5m of an infected stump (Lewis, 1990). Infected stumps should be clearly marked prior to planting. Stump avoidance is only recommended for managing tomentosus root disease – see Table 4.

[1] Pest Codes: DRA – Armillaria root disease, DRB – black stain root disease, DRL – laminated root disease (Douglas-fir strain), DRN – annosus root disease, DRT- tomentosus root disease.

1. Regenerating with less susceptible species

Tree species vary in their susceptibility to different root diseases (Cleary et al., 2008; Sturrock et al., 2006; Reich et al., 2013). Losses to host-specific root diseases, such as laminated root disease and tomentosus root disease, can largely be avoided by planting non-host species at the time of reforestation. Even with the wide range of susceptible hosts to Armillaria root disease, less susceptible species options can be favoured at the time of planting. Species conversion to less susceptible trees naturally occurs over time in both managed and unmanaged stands, but it can be facilitated through species selection prior to planting. Host susceptibility, future site productivity, climate change impacts, and other management considerations must be balanced when selecting species for reforestation.

2. Stump removal

Stump removal (also known as stumping) has repeatedly been shown to reduce root disease, in the majority of cases where it has been applied (Cleary et al., 2013; Vasaitis et al., 2008; Thies and Westlind, 2005; Shaw et al., 2012). When used appropriately, stump removal is justified and compensated by reducing mortality due to root disease and improving tree growth (Morrison et al., 1988). Under some tenure agreements, tenure holders can apply for a stumpage allowance if root disease is identified in the site plan. More than a dozen stump removal research trials have been conducted in the Kootenay/Boundary Region. Preliminary results suggest that stump removal in the moist subzones of the ICH yield the most pronounced increase in volume. A new cost-benefit study of Douglas-fir stands indicates that stump removal becomes profitable (net gain) where the site index exceeds 20-25 meters (Bogdanski et al., 2018).

A flowchart for considering stumping as a treatment option (Figure 1) has been developed to support decision making.

The use of experienced operators and large excavators with hydraulic, gripping thumb attachments and large tracks can help reduce soil compaction by minimizing machine movement and ground pressure (Thies and Sturrock, 1995), especially when it comes to the removal of larger stumps. Stump removal is recommended for trees up to 75 cm DBH (Beale, 1989), but the machine must be capable of handling a stump of that size. If tree size prevents the removal of all stumps in a stratum a treatment other than stumping must be selected. Uprooted stumps should be flipped and placed back in their original holes to allow the roots to dry. Windrowing or piling stumps reduces the number of plantable spots, may increase the risk of soil compaction, and can result in an uneven distribution of woody debris on the site. Large roots that break off during stump removal and hardwood stumps should be removed from the soil. Silvicultural systems that reduce the effectiveness of stumping (e.g., dispersed retention) should be avoided.

While stump removal can significantly reduce root disease, a number of negative site impacts may occur. Excessive site disturbance can increase the risk of introduction and spread of invasive plants. The disturbance of soil may result in erosion, puddling, compaction, inversion of horizons, and nutrient loss (Moffat et al., 2011). Stumping operations should be monitored frequently to avoid excessive site or soil disturbance and must be postponed after periods of heavy rain or snow. An assessment of site disturbance can be completed using the soil conservation survey. Access to the soil conservation survey can be found at:
https://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/soilsurv/soilconsurv.pdf.

It is highly recommended that a post-stumping survey be completed to ensure that the stumping treatment was adequate. It is more economical and efficient to conduct the post-stumping survey while the machines are still onsite. If the original treatment did not remove a sufficient amount of stumps, roots and debris, a second removal may be required. Leaving behind stumps, stubs or residual trees of any species must be avoided to reduce the probability of retaining potential sources of inoculum, thereby reducing stumping efficacy.

Stumping for root disease

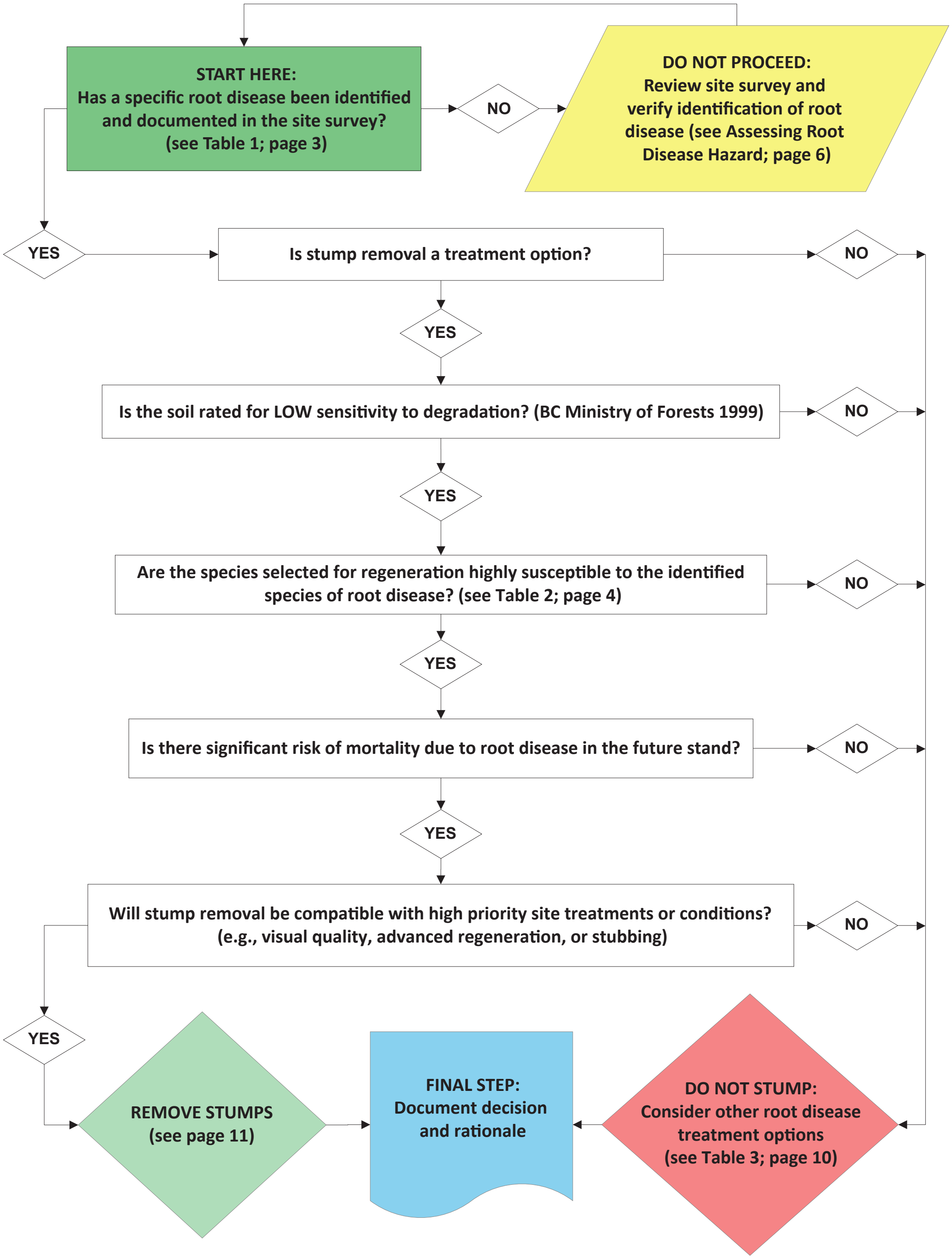

Figure 1: Stumping flowchart to aid in decision making. CAUTION: Stumping is not recommended on sites with low productivity or little evidence of pre-harvest root disease. Stumping should be limited to sites with non-calcareous, deep, light-textured soils, and slopes less than 30%. Stumping is only recommended for sites with a low risk of soil compaction, displacement, erosion and mass wasting. Hazard assessment keys exist for evaluating site sensitivity to soil degrading processes (B.C. Ministry of Forests, 1999).

3. Pushover harvesting

Pushover harvesting combines harvesting and stump removal in one step and is suitable for tree sizes up to 78 cm DBH (Sturrock et al., 2006). Provided that the amount of root removal is comparable, pushover harvesting can be as effective as post-harvest stump removal in reducing root disease. There is also less risk of leaving tree roots in the ground because of missed stumps. The costs involved in pushover harvesting on the coast were found to be similar to conventional harvesting costs (Sturrock et al., 1994). However, depending on the size of trees being harvested, excavators may be required to provide additional protective structures against falling objects that exceed the specifications of commercially available attachments.

4. Facilitating hardwood regeneration

Hardwoods appear to limit the spread of root disease between conifers. Although the underlying mechanisms are poorly understood, hardwoods are less susceptible to infection and more tolerant to disease (Cleary et al., 2008; Morrison et al., 2014; Morrison et al., 1992). As a comparatively resistant species, the roots of birch can form a barrier to underground disease movement (Morrison et al., 1992; Morrison and Mallett, 1996). Highly susceptible hosts, such as Douglas-fir, benefit by having such impediments to disease spread.

Morrison et al. (1988) suggested the spread of laminated root disease and Armillaria were prevented when rows of Douglas-fir or pine were alternated with rows of cedar or birch. Conversely, birch removal treatments led to an increase of Armillaria on Douglas-fir (Baleshta et al., 2015; Baleshta et al., 2005; Simard et al., 2001).

5. Biological control

Biological controls are introduced agents that can displace or prevent colonization by pathogenic fungi and prevent the spread of disease. Biological agents are considered pesticides and, as such, must go through the same regulatory approval process and be registered for use by the federal government.

An example of a product that is registered for use in forestry in BC is *Phlebiopsis gigantea*. Commercially available formulations of *P. gigantea* are available in Canada and can be used to prevent colonization of freshly cut stumps by the pine-type of annosus root disease (*Heterobasidion irregulare*).

6. Stump avoidance

This strategy involves avoiding stumps when planting and is recommended for sites infected by tomentosus root disease only. The probability of infection by tomentosus has been shown to be inversely proportional to the distance from an infected stump (Lewis, 1990). At a distance of 5 m, the probability of infection is low; however, the effective distance may vary depending on stand age and other stand qualifiers.

Not Recommended Treatments

Table 4 summarizes treatments that require more research and are not currently recommended for use in managing root disease in BC. Please contact the Regional Pathologist responsible for the management area with any questions. More information on each of these treatments and a brief rationale for not recommending use can be found in Appendix 5.

Table 4: Treatments not recommended for the major root diseases in British Columbia.

Tactic	Disease[1]	Comments
Ring barking	DRA	Trials are needed to assess whether this is an effective treatment or not. Needs more research.
Biological control	DRA	Requires more research and regulatory approval. Not recommended. (Currently, only *Phlebiopsis gigantea* is registered for use to control *Heterobasidion irregulare* in Canada.)
Fertilization	DRA, DRL	Needs more research.
Resistance/tolerance	DRA, DRL	No resistant stock is currently available. Needs more research. Not recommended.
Accelerating stump decomposition	DRA, DRB, DRL, DRN, DRT	Has not been shown to be effective. Needs more research.
Stump avoidance	DRA	**For Armillaria root disease, there is no proven effective distance from an infected stump.** Needs more research. Stump avoidance is only recommended for managing tomentosus root disease.
Stump fumigation	DRA, DRL	No registered chemicals.
Broadcast burning to reduce inoculum	DRA, DRB, DRL, DRN, DRT	Only reduces inoculum close to the surface. Not recommended.
Stump removal with root raking	DRA, DRL, DRN, DRT	Heavy soil disturbance and expensive.

[1] Pest Codes: DRA – Armillaria root disease, DRB – black stain root disease, DRL – laminated root disease (Douglas-fir strain), DRN – annosus root disease, DRT- tomentosus root disease.

Considerations for Intensive Silviculture Treatments

Intensive silviculture treatments are **not recommended** in portions of stands that contain root disease. Attempts to reduce root disease inoculum during stand tending operations are expensive and largely ineffective. Any potential economic gains anticipated from intensive silviculture treatments, such as fertilizing, spacing or pruning, may be reduced by future losses from root disease. Fertilization and broadcast burning are included in Table 4 as two silviculture treatments that are not recommended.

1. Manual brushing on sites with Armillaria root disease

Manual brushing of hardwoods has been associated with increased levels of Armillaria (Simard et al., 2005; Baleshta et al., 2015; Woods, 1994). However, Simard et al. (2005) found that the combination of brushing and glyphosate application as a treatment for hardwood competition did not result in an increase of Armillaria after five years. Selective manual brushing (Baleshta et al., 2005) or brushing as soon as possible after regeneration (when deciduous root systems are small) may help minimize increases in Armillaria incidence. Manual brushing should only be prescribed when necessary to prevent acute competition with preferred and acceptable species, or when necessary to meet free growing. Prompt reforestation after harvesting may reduce the need for subsequent brushing treatments. **On the coast, brushing may be an acceptable silviculture treatment in areas with root disease due to the higher level of vegetative competition.**

2. Spacing on sites with Armillaria root disease

Spacing can also increase the level of Armillaria root disease in a stand. Cruikshank et al. (1997) found that high percentages of stumps in spaced Douglas-fir stands were colonized by Armillaria and that, depending on the BEC zone and stump root size, 44-71% of stump roots transferred mycelium to crop trees. Rosso and Hansen (1998) also found higher Armillaria-caused mortality following spacing in Douglas-fir. Other studies have shown no significant increase in Armillaria-caused mortality after spacing (Blenis, 2000; Filip and Goheen, 1995). The literature is not conclusive, but **spacing is not recommended** on sites with Armillaria root disease.

Free-Growing Obligations and Root Disease

The root disease management options outlined in this document are long-term investments that can help maintain the productivity of forests by reducing the impacts of root disease. The chosen treatments must result in a forest that meets or exceeds the standards for species composition and health as assessed by the ministry's Free Growing Survey (revised April 1, 2016.). Achieving free-growing status is an administrative forest management obligation. If young trees are clearly showing signs of root disease at the typical free-growing age of 8-12 years, the future productivity of the stand will be significantly compromised. Therefore, it is beneficial to select site-specific root disease treatments that are based on the scientific information and recommendations provided in this document.

During free-growing surveys, surveyors are responsible for identifying which root disease is present and for knowing which tree species are susceptible. Both the total count of susceptible species and the number of infected, symptomatic trees per plot is recorded. The presence of root disease in young trees at the time of the free-growing survey means that root disease will spread and affect other susceptible trees until harvest. To account for this spread over time, the ratio of susceptible species over the number of infected trees is calculated. This ratio is then multiplied by a species-specific multiplier which will vary by BEC zone. The multiplier is used to estimate the number of adjacent trees which likely are, or will be, infected by the disease by considering the virulence, growth rate, and mode of spread, and providing an estimate of how many adjacent asymptomatic trees may be infected. This information is then used to determine if the plot meets the minimum density target and if the stand will be considered healthy and productive enough to achieve free-growing status. For more information, refer to Free Growing Damage Criteria (revised July 6, 2014.)

Young trees killed by Armillaria root disease under powerline near Horsefly, BC

Glossary

Term	Definition
Asymptomatic	The lack of expression of external signs or symptoms related to infection; effectively “without symptoms.”
Disease incidence	The proportion or percentage of diseased entities within a sampling unit. For example, number of trees infected in a population.
Disease intensity	The amount of disease present within a specific area. Disease incidence and severity are attributes of intensity.
Disease severity	The quantity of disease affecting entities within a sampling unit. For example, the number of infected roots on a tree.
Hazard	The probability that a root disease is present at a site.
Inoculum potential	The energy available to a fungus that supports the infection of a host and the growth and maintenance of fungal tissue. This energy is critical to ensure the fungus can overcome tree defenses (i.e., more food = higher probability of infection).
Occurrence	The presence or absence of a disease, not its quantity.
Risk	The probability of fungal infection of the tree roots based on three site-specific factors: presence of root disease fungi, proximity to susceptible hosts and favourable environmental conditions.

Levels of Susceptibility

The following terms are used to describe the relative scale of host tree susceptibility, and represent the likelihood of mortality. These definitions are generalized to improve the understanding and separation of the terms.

Term	Definition
Susceptible	Trees are subject to infection by a root disease fungus. A relative scale ranging from high susceptibility to low susceptibility. Tree mortality is likely for highly susceptible species and less likely for tree species of intermediate to low susceptibility.
Tolerant	Trees are more likely to survive when infected.
Resistant	Trees are less likely to become infected.
Immune	Trees are unlikely to become infected.

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Appendices

Appendix 1: Supporting references

Stand establishment decision aids (SEDAs)

The SEDAs for Armillaria root disease, black stain root disease, laminated root disease, and tomentosus root disease can be found using the links below:

Armillaria root disease: http://www.jem-online.org/forrex/index.php/jem/article/view/397

Black stain root disease: http://www.jem-online.org/forrex/index.php/jem/article/view/308

Laminated root disease (coastal): http://www.jem-online.org/forrex/index.php/jem/article/view/357

Laminated root disease (interior): http://www.jem-online.org/forrex/index.php/jem/article/view/94/79

Tomentosus root disease: http://www.jem-online.org/forrex/index.php/jem/article/view/562

Additional references

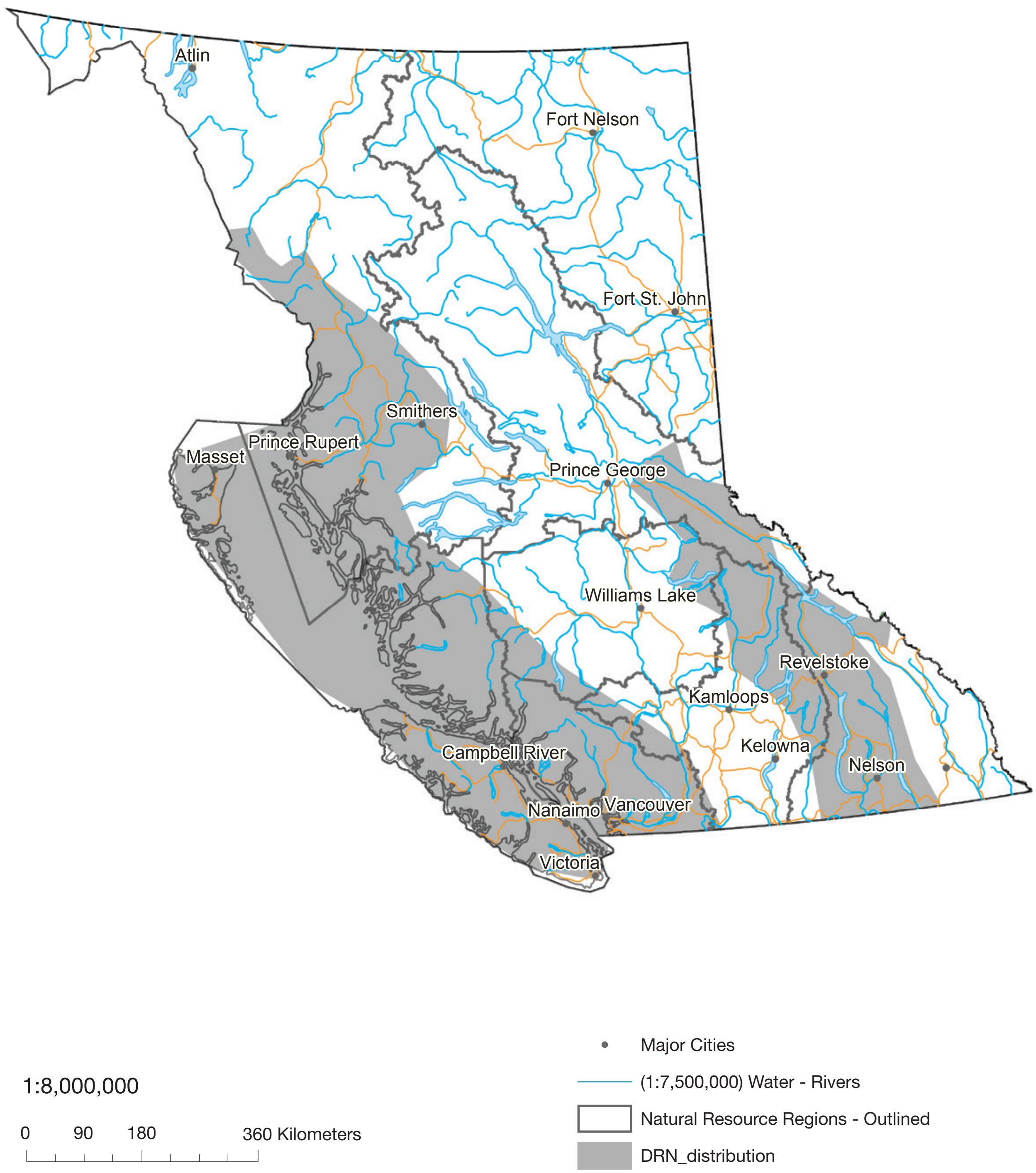
The following references are not formal SEDAs; however, they provide information that is relevant to root disease management in BC.

Annosus root disease: http://forestpests.org/acrobat/annosus.pdf

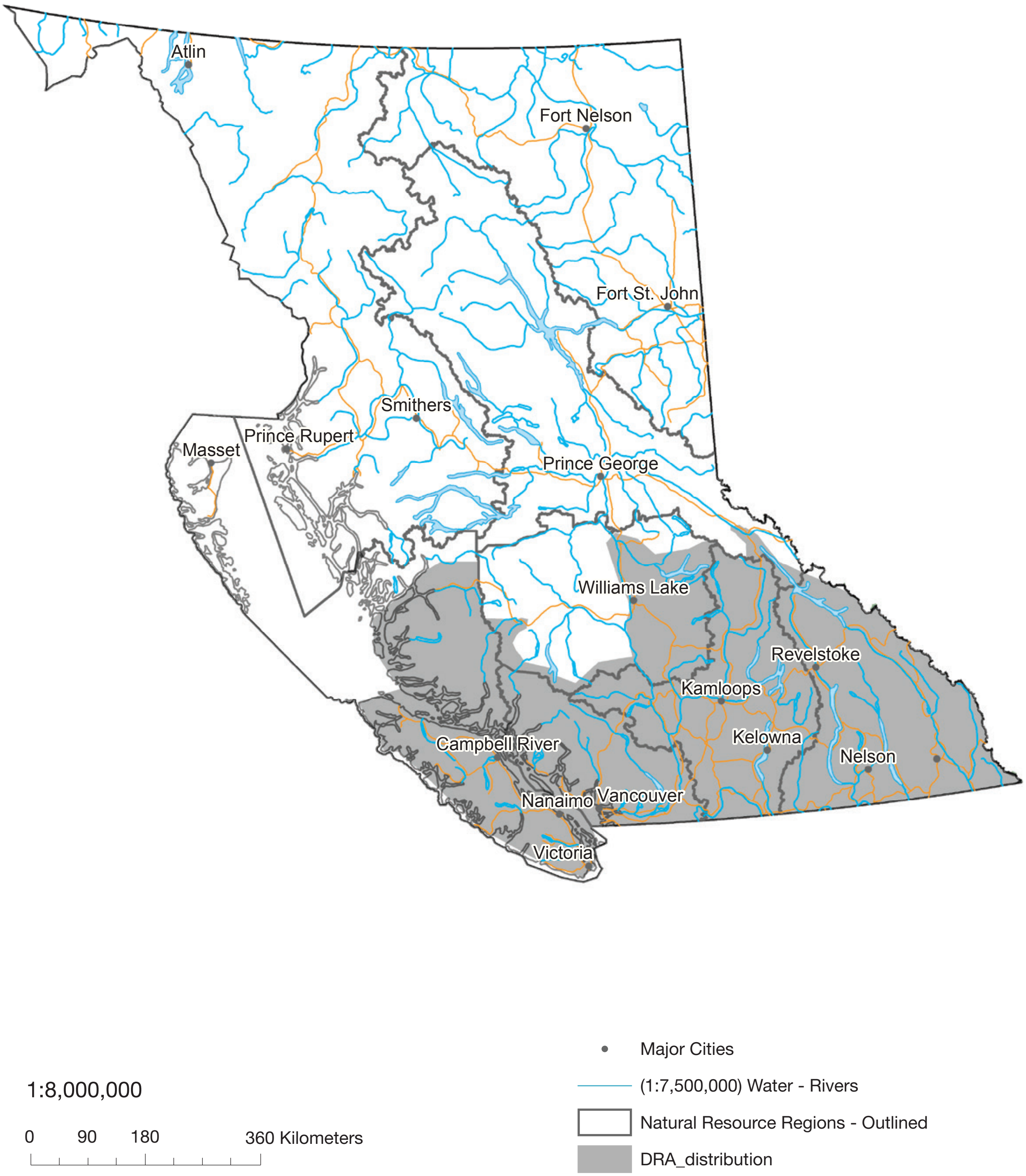
Black stain root disease: http://cfs.nrcan.gc.ca/publications/download-pdf/4201

Appendix 2: Distribution maps

Annosus root disease (*Heterobasidion occidentale*) (DRN - S-type)

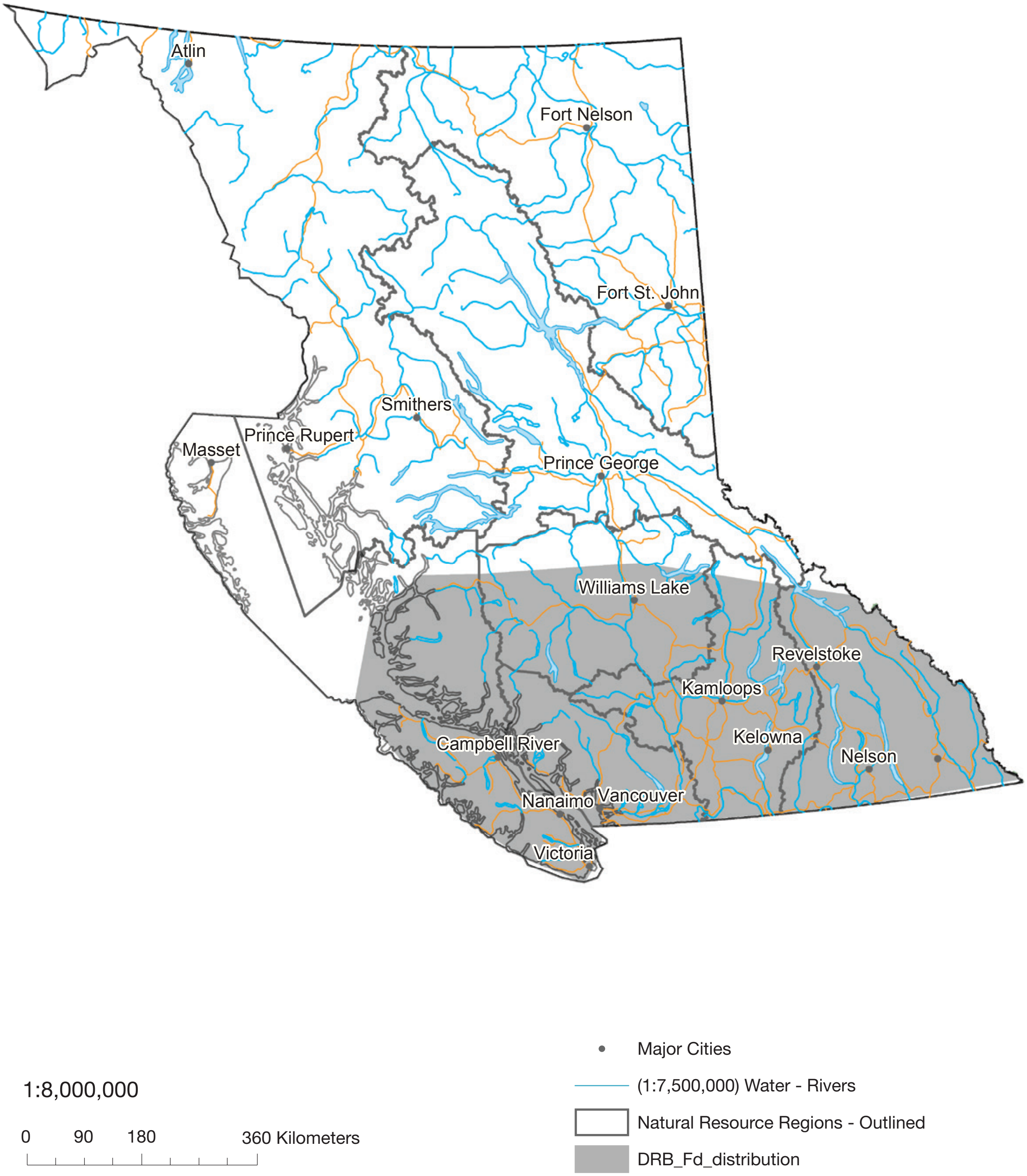


Armillaria root disease (*Armillaria ostoyae*) (DRA)

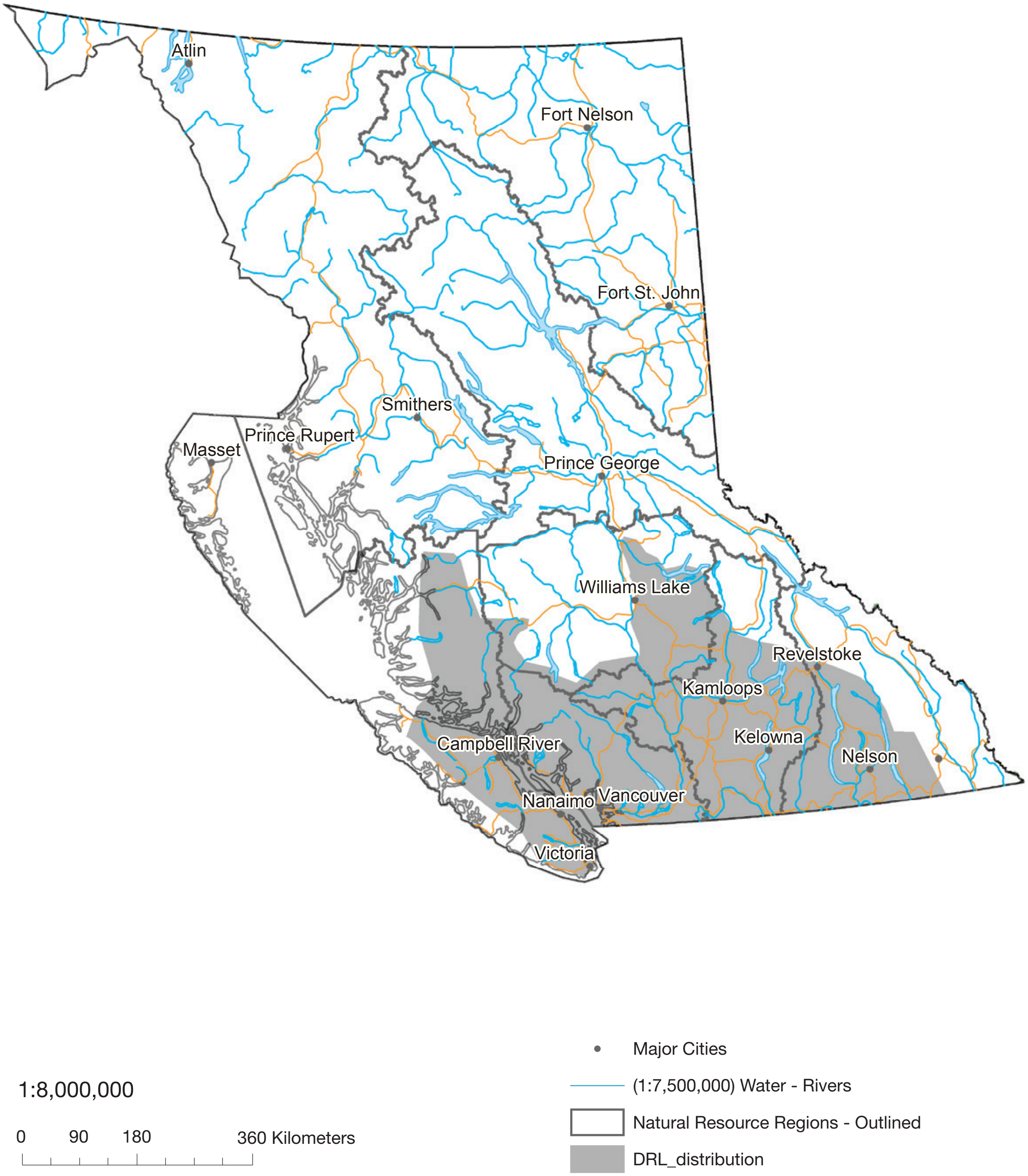


Black stain root disease (*Ophiostoma wageneri*) (DRB - Pine strain)

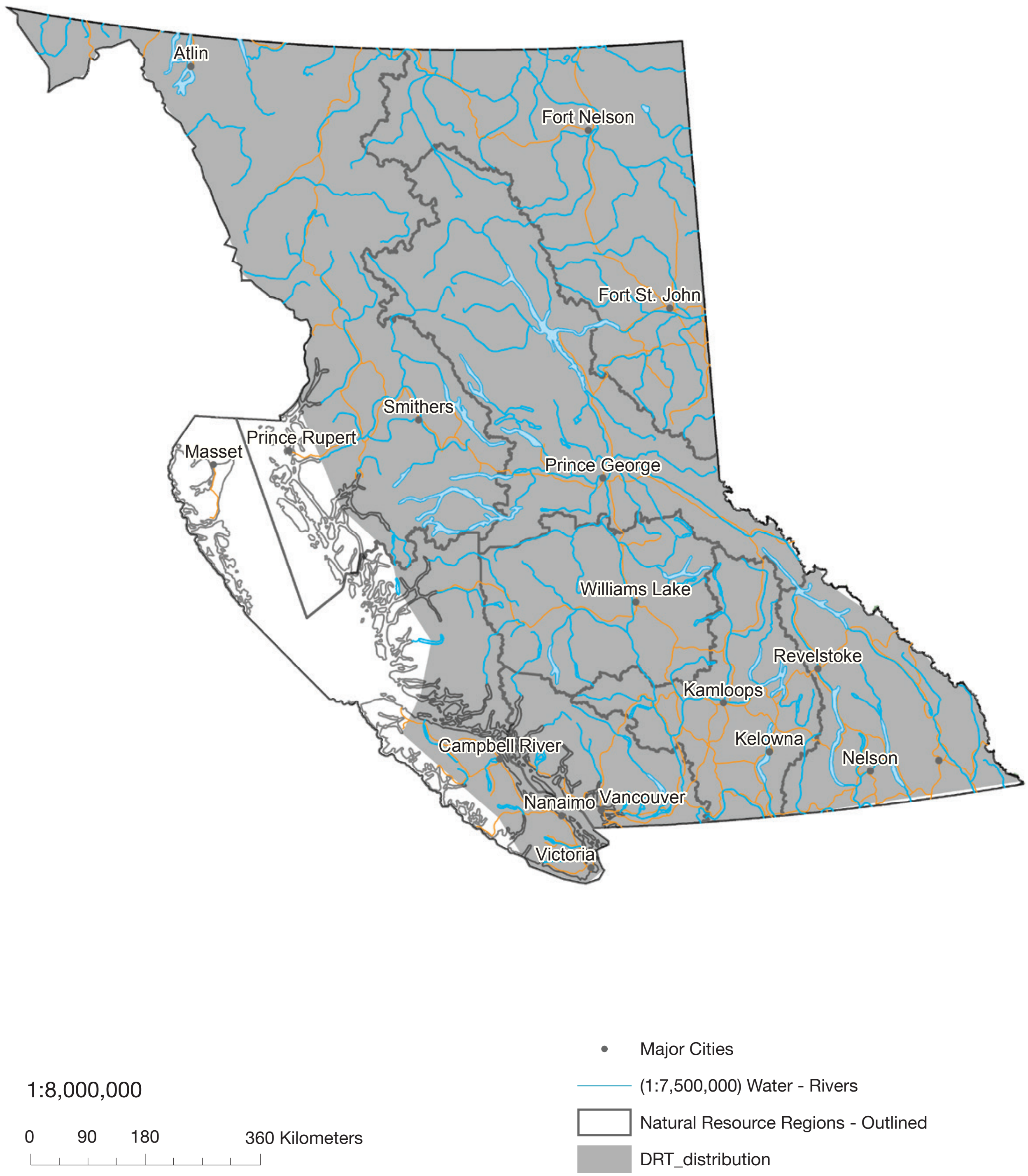
Black stain root disease (*Ophiostoma wageneri*) (DRB - Douglas-fir strain)



Laminated root rot (*Phellinus sulphurascens*) (DRL - Douglas-fir strain)



Tomentosus root rot (*Onnia tomentosa*) (DRT)



Appendix 3: Regional hazard tables

The following tables provide an estimate of root disease **hazard** for select BEC variants by forest region. In the context of the tables, root disease hazard can be considered as the probability of encountering root disease if susceptible hosts are present. BEC variants with an H next to them indicate ecosystems where root disease site assessments should be conducted during the preparation of plans and prescriptions. The probability of **hazard** does not indicate the **risk** of root disease; to assess risk, the site must be assessed. Sites with no root disease have a low risk of root disease in the next rotation, regardless of hazard.

Root disease hazard by BEC subzone in the Cariboo Forest Region

BEC zone	BEC subzone	Annosus root disease	Armillaria root disease	Black stain root disease	Laminated root disease	Tomentosus root disease
ICH	dk		H		H	
	mk3		H[1]		H[1]	H
	mw3		H		H	
	wk2		H[1]		H[1]	
IDF	dw				H[2]	
SBS	dk					H
	dw1		H[1]		H[1]	H
	dw2					H
	mc					H
	mh					H
	mw					H
	wk1					H

H[1] = warm south-facing slopes are the highest hazard potential.
H[2] = west of Mosley Creek drainage.

Root disease hazard by BEC subzone in the Thompson/Okanagan Forest Region

BEC zone	BEC subzone	Annosus root disease	Armillaria root disease	Black stain root disease	Laminated root disease	Tomentosus root disease
ICH	dw3		H			
	mk1		H		H	
	mk2		H		H	
	mw2		H		H	
	mw3		H		H	
	vk1		H^2			
	wk1		H^2			
IDF	dk1		H		H	
	dk2		H		H	
	dm1		H		H	
	mw1		H		H	
	mw2		H		H	
	xh1		H^1		H^1	
	xh2		H^1		H^1	
MS	dm1		H^1			
	dm2		H^1			

H^1 = Douglas-fir leading sites only.

H^2 = Hazard is low north of Pyramid on the North Thompson River.

Root disease hazard by BEC subzone in the Kootenay/Boundary Forest Region

BEC Zone	BEC Subzone	Annosus root disease	Armillaria root disease	Black stain root disease	Laminated root disease	Tomentosus root disease
ESSF	dc1		H	H		
	dk1		H			H
	wc1		H			
	wm		H			
IDF	dk			H	H	
	dm1	H	H	H		
	dm2	H	H			
	mw				H	
	wm					H
	ww				H	
	xh1		H[1]		H[1]	
ICH	dw		H		H[1]	
	mk1		H	H		
	mw		H		H	
	vk1		H			
	wk		H		H	
	xw		H			H
MS	dc			H		
	dk		H			
	dm		H	H		
	xk			H		
PP	dh1			H	H[1]	
	dh2			H	H[1]	

H[1] = Douglas-fir leading sites only.

Root disease hazard by BEC subzone in the Omineca & Northeast Forest Regions

BEC zone	BEC subzone	Annosus root disease	Armillaria root disease	Black stain root disease	Laminated root disease	Tomentosus root disease
BWBS	dk1					
	dk2					
	mw1					H
	mw2					
ICH	mm		H			
	wk1		H			
SBS	dh		H			H
	dk					H
	mw					H
	mk1					
	mk2					
	mc2					H
	mc3					H
	wk1					H
	wk2					
	wk3					

Root disease hazard by BEC subzone in the Skeena Forest Region

BEC zone	BEC subzone	Annosus root disease	Armillaria root disease	Black stain root disease	Laminated root disease	Tomentosus root disease
ICH						H
SBS						H
CWH						
All						
ESSF						

Root disease hazard by BEC subzone in the South Coast Forest Region

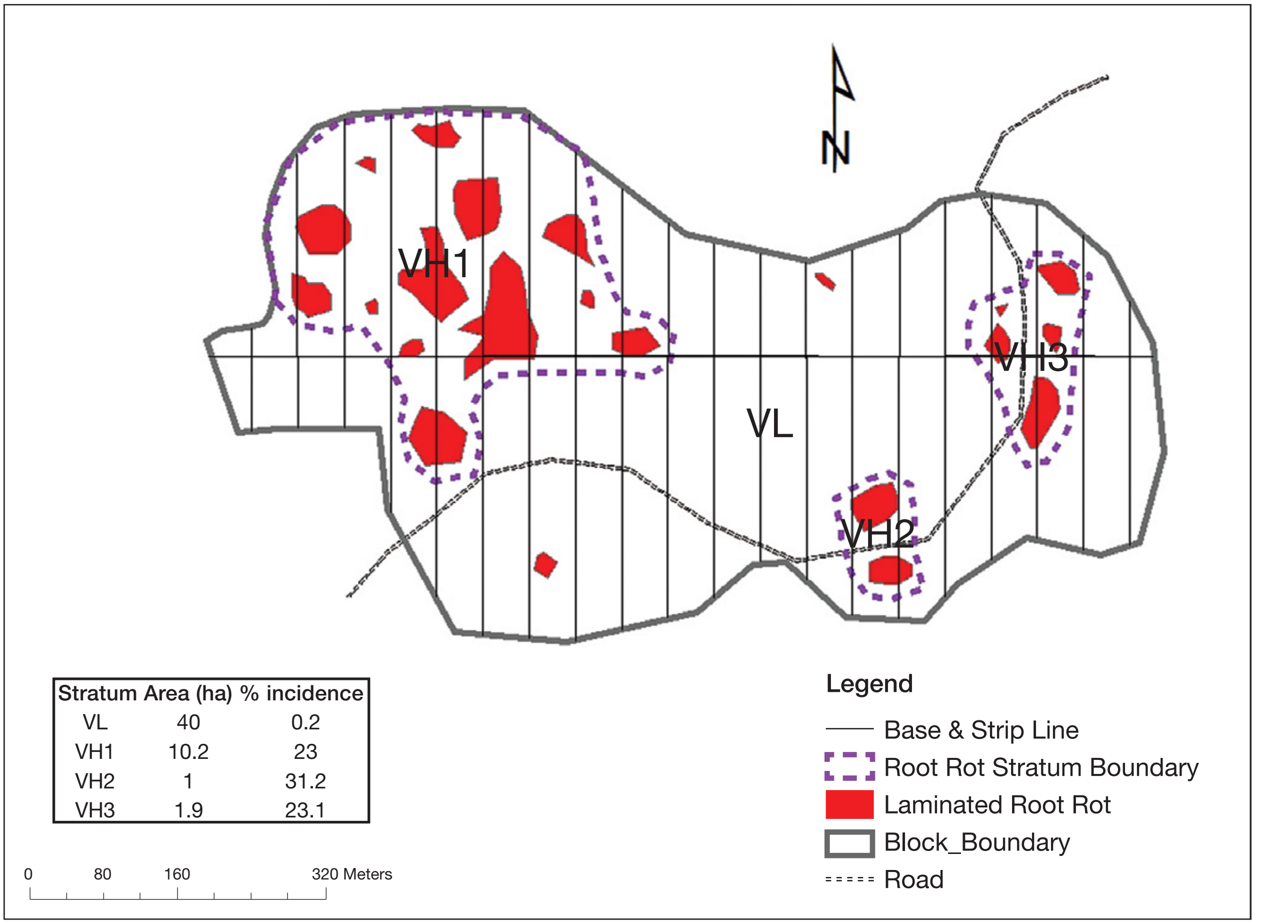
BEC zone	BEC subzone	Annosus root disease	Armillaria root disease	Black stain root disease	Laminated root disease	Tomentosus root disease
CDF	mm		H		H	
CWH	dm		H		H	
	ds1		H		H	
	ms1		H		H	
	ms2		H		H	
IDF	ww		H		H	

Root disease hazard by BEC subzone in the West Coast Forest Region

BEC zone	BEC subzone	Annosus root disease	Armillaria root disease	Black stain root disease	Laminated root disease	Tomentosus root disease
CDF	mm		H		H	
CWH	mm1		H		H	
	mm2		H		H	
	xm1		H		H	
	xm2		H		H	

Appendix 4: Sketch map example of stratification of root disease

Figure 2 shows an operational root disease map created from data collected during an area-based strip line survey of laminated root disease. The purpose of the map is to delineate root disease treatment strata based on root rot survey results. As in this example, treatment strata are often based on areas of similar root disease incidence, but other site factors that affect treatment options can also be important considerations (e.g., slope, soil texture, barriers such as creeks or roads, suitability of planting for alternative species, other values, etc.). These strata then serve as the basis for defining treatment options.



Stratum	Area (ha)	% incidence
VL	40	0.2
VH1	10.2	23
VH2	1	31.2
VH3	1.9	23.1

Figure 2: Sketch map with stratified disease centers of laminated root disease.

Appendix 5: Rationale for treatments that are not recommended

The following treatments are not recommended for managing root disease in BC. The information below applies to the treatments summarized in Table 4 (page 15). This information is provided to help forest professionals and practitioners understand the implications of these treatments and the reasons they are not recommended for use.

1. Ring barking

Ring barking is the removal of cambium and phloem in a ring around the tree to starve the tree of nutrients used by the invading fungus. Further work is needed to confirm whether ring barking could be used to reduce the level of Armillaria in Douglas-fir forests before this can be recommended as a treatment.

2. Biological control

Biological controls are introduced agents that can displace or prevent colonization by pathogenic fungi and prevent the spread of disease. Biological agents are considered pesticides and, as such, must go through the same regulatory approval process and be registered for use by the federal government. Currently, only *Phlebiopsis gigantea* is registered for use to control *Heterobasidion irregulare* in Canada. Biological control for root disease requires more research and is not recommended at this time.

The following two examples are not registered for use in BC and are therefore not recommended treatments. Additional research is required to assess the potential for application in BC forestry.

Control of Armillaria root disease with *Hypholoma fasiculaire*

Hypholoma fasiculaire has been applied to stumps to test its efficacy for controlling Armillaria root disease. Chapman et al. (2004) placed sawdust inoculated with *H. fasiculare* next to cut stumps and then compared seeding mortality in treated and untreated areas. *H. fasiculaire* successfully colonized some stump roots and the treatment resulted in significantly less seedling mortality at two of six sites.

Control of laminated root disease with *Trichoderma viride*

Nelson and Thies (1985) selected stumps infected with laminated root disease and implanted them with wood dowels and sterilized barley inoculated with *T. viride* to determine if *T. viride* would move into the stumps and compete with the fungus responsible for laminated root disease (*Phellinus sulphurascens*). Although the stumps were successfully colonized by *T. viride,* a greater degree of colonization of the lower stump and major roots would be necessary to achieve biological control.

3. Fertilization

The interactions between fertilizer application and root disease development are complex. Higher nitrogen levels in soils and nitrogen fertilization have been correlated with both higher (Entry et al., 1991a; Mallett & Maynard, 1998) and lower incidences of Armillaria root disease (Entry et al., 1991b; Singh, 1983; Shields and Hobbs, 1979). Some authors have suggested that increased incidence of Armillaria following nitrogen fertilization can be attributed to poor nitrogen to potassium ratios and/or reduced phenol to sugar ratios, and that fertilizing with both nitrogen and potassium or potassium alone could reduce incidences of Armillaria root disease. Shaw et al. (1998) showed that Douglas-fir seedlings fertilized with high nitrogen and low potassium had significantly lower concentrations of phenolics and tannins (important plant defense compounds), and lower ratios of these compounds to sugars in the root tips than seedlings receiving high amounts of potassium. More work is needed before fertilization can be recommended as a treatment in stands infected by Armillaria. Application of nitrogen seems to have no effect on the development of laminated root disease (Thies et al., 1994).

Spot application of fertilizer to enhance stump decomposition is a common practice in horticulture but **has not been proven** in forestry use to control root disease (see Accelerating stump decomposition).

4. Resistance/tolerance

There is growing interest in breeding resistance or tolerance to root disease based on the evidence of variation in resistance among host families to both laminated root disease and Armillaria (Cruikshank et al., 2010; Sturrock, 2005). Screening programs are in the early stages of testing and no resistant or tolerant planting stock has been developed. Resistance and tolerance to root disease can increase with age for some tree species. For example, larch trees over 20-25 years of age show a marked decrease in susceptibility to Armillaria compared to younger trees (Cleary et al., 2008).

5. Accelerating stump decomposition

Cutting grooves or drilling holes in stumps and adding nitrogen fertilizer are commonly used back yard methods to speed up stump decomposition. It is unclear whether such techniques would be effective in reducing root disease in a forestry situation. Until such research is carried out, this activity is not recommended as an effective root disease treatment.

6. Stump avoidance

At the present time, stump avoidance is only recommended for tomentosus root disease (see Recommended Treatments; Table 3 (page 10).

This strategy involves avoiding stumps when planting. Buffer distance will vary depending on the type of root disease, susceptibility of the planted species, and stump size. Infected roots associated with larger stumps occupy more area and may contain viable inoculum potential for a longer period of time.

In the case of Armillaria root disease, it is difficult to identify infected stumps post-harvest. There is no effective distance from a stump infected by Armillaria at which trees can be planted to reduce stump inoculum contact (Morrison et al., 2000). Roots of large trees can spread meters from the base and overlap other roots resulting in large areas being at risk of infection.

7. Stump fumigation

Chemical fumigation is commonly used to reduce root and other soil-borne diseases in nurseries and agricultural settings. Over the years, various researchers have attempted to reduce stump inoculum by using chemical fumigants (Thies and Sturrock, 1995; Filip and Roth, 1977). The cost of chemical fumigation limits their use in forestry operations. **Currently, there are no fumigation chemicals registered for root disease treatment in BC.**

8. Broadcast burning to reduce inoculum

Burning stumps has no significant effect on seedling mortality caused by Armillaria root disease. Whitney and Irwin (2005) found that the number of saplings killed by Armillaria 10 years after a prescribed burn was not significantly different for seedling mortality at an unburned site with endemic Armillaria. They also found that there was no significant difference for mortality between severely burned, moderately charred, and lightly scorched stumps. Broadcast burning and burning stumps is not an effective method for reducing stump inoculum.

9. Stumping with root raking

Many early stumping trials combined root raking with stump removal. In later trials, it was considered unnecessary, too expensive, and resulted in excessive soil disturbance. Hence, root raking is not recommended at this time due to conflicting evidence, variability in treatment efficacy, and excessive soil disturbance.